

# SOIL SCIENCE

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## SOIL SCIENCE



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#### ERRATA

*Secular and Seasonal Changes in the Soil Solution*, by John C. Burd and J. C. Martin  
SOIL SCIENCE, vol. XVII, no. 2, August, 1924, p. 151-167

Page 152, line 7 should read, "at both high and low moisture contents."

Page 152, footnote, should be "E. A. Fisher."

Page 153, in paragraph 3, line 7 should read "and to the portions."

Page 161, last line should read "soil continues to give."

*The Availability of Nitrogen in Peat*, by C. B. Lipman and M. E. Wank  
Reference 12, p. 316, should read Waynick instead of Wayrick



## DRYING OF SOIL, AS ONE OF THE NATURAL FACTORS IN MAINTAINING SOIL FERTILITY<sup>1</sup>

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Received for publication February 25, 1924

During the last 25 years many authors have found that heating a soil to relatively low temperatures or treating it with weak antiseptics is accompanied by a marked increase in fertility. On one hand, this depends on the increase in solubility of some of the soil constituents, primarily organic nitrogenous compounds, and on the other hand on the change in the biological processes in the soil. It is well to point out in this connection the work of Dehérain, Demoussy, Richter, Russell and Ritter. Since the ordinary air-drying of soil also has a marked effect upon the solubility of nitrogenous constituents of the soil (analyses of our laboratory in 1910) and is capable of bringing about its partial sterilization, it seemed quite possible that the air-drying of soil should also manifest itself in an increase in its fertility. On the basis of the aforesaid, the problem has been studied during the years 1915 to 1920 in the chemical laboratory of the Shatiloff Agricultural Experiment Station. The results obtained have been published in the form of five communications in "The Experiment Station News" (2). The present paper represents the first general summary of the results obtained.

### I

The experiments were conducted in the following way. The soil sample was taken in spring (April or May) from several places in a definite experimental plot. A depth of 3 or 4 vershoks<sup>3</sup> was sampled by means of a broad cylindrical auger, thus insuring a representative of the different depths of the plowed layer. The soil from the various borings was mixed, sifted through a  $\frac{1}{16}$  mm. sieve to remove the roots and to insure better mixing; then it was separated into two equal parts. One part was left in the barn on a canvas, covered to diminish evaporation; the other was carried to the greenhouse, spread out in thin layers on iron sheets and left there exposed to light and air until completely dry. During sunny days this was accomplished in 1 or 2 days; in cloudy weather it required from 4 to 5 days. The dried soil was then placed in canvas bags

<sup>1</sup> Translated from the Russian by Mrs. B. Trajkovich and J. S. Joffe, New Jersey Agricultural Experiment Station.

<sup>2</sup> Northern black soil district of Russia.

<sup>3</sup> A vershok equals 1.75 inches.

and moisture determinations made on it and also on the moist sample. In most cases the moisture content of the dry soil was found to be 3 to 6 per cent (on the basis of the absolutely dry substance); the moisture content of the moist soil varied from 25 to 35 per cent.

Each one of the soil samples was packed into Wagner glass or zinc pots with sand drainage and irrigation from below. In filling each of the pots sufficient dry or moist soil was taken to give equal amounts of absolutely dry soil. In order to obtain uniform packing, the wet and dry soils were moistened by mixing in pans with an amount of distilled water to make up a 35 per cent moisture content. From each of the samples taken in the field, four pots were made up: two with moist and two with dry soil.

The pots were then sown with millet<sup>4</sup> and watered daily so as to maintain an optimum moisture content equivalent to 33 per cent of the absolute dry weight of the soil (60 per cent of its total water-holding capacity). Watering was done with local well water, which, as shown by special experiments, scarcely raises the yield as compared with distilled water. When ripe, the millet was harvested, brought to a constant weight in special cupboards at the temperature of 60°C., weighed and thrashed by hand, after which the weight of the grain was determined.

During the years 1915 and 1918, when a general survey of the effects of drying was carried out, 81 samples from plots widely differing in their cultural condition were tested. During the year 1915, 2 samples were tested; during 1916, 18; during 1917, 58; and during 1918, 3 samples. On the basis of the yield of the wet soil sample as a check, the percentage increase or decrease in the yield of the dried soil sample, designated as the effect of drying, was obtained. Table 1 gives a summary of the results for 4 years.

It is evident that *the average effect of drying* in all experiments performed *is expressed in an increased yield* in the dried samples over the undried, amounting to 45 per cent for the total weight of crop, and 41 per cent for the grain alone. Besides, very large increases (127 per cent for the total weight and 123 per cent for grain) were obtained in 12 to 14 per cent of all the observations; medium increases (44 per cent for total weight and 44 per cent for grain) were found in 55 to 57 per cent of all the observations; small increases (10 per cent for total weight and 12 per cent for grain) were found in 22 to 24 per cent of all the observations; decreases in yield (2 per cent for total weight and 10 per cent for grain) were established in 5 to 11 per cent of all the observations. It is important to note that while the decrease in yield was expressed in most cases in insignificant figures of 2, 5 and 7 per cent, in the observations of large increases, doubling and trebling of yields occurred.

In this manner *in a large number of the observations the drying of the soil was accompanied by an increase in the yield of millet (also of oats and buckwheat) under the conditions present in the pot experiments.*

<sup>4</sup> In three cases buckwheat and oats were taken as plants for observation; however, since both of these plants, as it will be shown later, responded like millet to drying, the data have been compiled together.

TABLE 1  
Increase in yield on dried soil samples as compared with undried

GROUPS ACCORDING TO THE MAGNITUDE OF THE EFFECT OF DRYING	AVERAGE EFFECT OF DRYING				NUMBER OF CASES				THE MAGNITUDE OF THE EFFECT OF DRYING FOR INDIVIDUAL CASES							
	Total for all groups		According to combination of groups		In per cent		In absolute figures		On the basis of weight of grain				On the basis of total weight of yield			
	For grain	For total weight	For grain	For total weight	For grain	For total weight	For grain	For total weight	1918	1917	1916	1915	1918	1917	1916	1915
									per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
<0										0, 6, 7, 5, 16, 9, 6, 13		-33	10	2, 0, 5		-1
1-20									8	19, 19, 12, 15, 16, 14, 9, 4, 13	19, 13, 13, 4, 11, 10, 8		10	1, 7, 9, 13, 8, 4, 17, 6, 8, 14, 17	12, 20, 7, 11, 18, 1	
21-40									31	39, 28, 25, 40, 21, 25, 29, 30, 39, 31, 29, 36, 29	24, 37, 26, 27, 29, 33, 30, 34			39, 39, 33, 26, 26, 23, 38, 37, 22, 21, 32, 40, 30	30, 28, 33, 23, 22, 33, 33, 27	
41-60	41	45	44	44	17	24	14	20		41, 49, 50, 56, 56, 47, 47, 44, 54, 54, 50, 44, 51	47		45	44, 43, 53, 58, 55, 44, 52, 56, 42, 56, 42, 58, 57, 45, 44, 35, 41	53, 56	
61-80									66	68, 61, 67, 67, 67, 68, 72, 71				62, 77, 66, 76, 71, 76		
81-100										86, 96, 95, 86			83	98, 86		87
>100										150, 139, 178	104, 171	121		134, 102, 164, 148, 183	105, 203	

## II

The soils used for the experiments without exception belonged to the experimental field of the station and therefore were genetically homogeneous, but, as already mentioned, they differed greatly in culture.

The station soil represents the middle-Russian tzernoziem of the northern half of the tzernoziem district with the following characteristic properties:

Depth of horizon A .....	40 cm.
Depth of horizon B .....	60 cm.
Humus .....	8-20 per cent
Total N .....	0.48 per cent
Total $P_2O_5$ .....	0.12 per cent

According to their previous cultivation, the soil samples used in the experiments may be classified under five main groups (for all groups plots were taken which had never received any manure or mineral fertilizers): (a) for many years a natural sod, (b) plots bearing perennial grasses, (c) plots sown year after year with the same plant, (d) plots subjected to a 3-year rotation and fallowing, (e) unsown plots kept continuously in fallowing. The effect of drying expressed in the percentage increase in yield of the dried samples as compared with corresponding undried samples, turned out to be as follows:

	TOTAL WEIGHT	GRAIN
	per cent	per cent
Uncultivated land (18 years) .....	241	229
Two and three years' grass culture .....	161	148
Continuous cropping with the same plant (5 to 6 years) .....	138	133
Three-field rotations (fallow-rye-oats) .....	122	117
Continuous fallowing (3 to 5 years) .....	124	128

In the 3-field rotations besides the unfertilized plots, experiments with manured plots (2400 poods<sup>5</sup> three times in 18 years), phosphate (9 poods  $P_2O_5$  two times in 6 years), and superphosphate (3 poods  $P_2O_5$  two times in 6 years) were conducted.

The effect of drying on these plots was obtained as follows:

	per cent
Manured .....	145-141
Fertilized with phosphate .....	143-143
Fertilized with superphosphate .....	128-131
Unfertilized .....	122-117

From the above cited figures it is evident that *the effect of drying is to a great extent dependent on the cultural conditions of the soil.* Besides: (a) The soils in an uncultivated condition appeared to be more sensitive to drying. (b)

<sup>5</sup> One pood equals 36 pounds.

The same is observed in soils occupied by cultural perennial grasses, but to a somewhat smaller extent. (c) Soils under ordinary methods of tillage are less susceptible to drying and its effects depend but little on the rotation. (d) The application of manure and phosphoric acid increases markedly the effect of drying.

As already stated, the effect of drying is determined by the increase in yield as compared with the yield on the undried sample. Thus the magnitude of the effect is dependent upon the yielding capacity of the moist sample, and with two equal increases expressed in absolute figures, the lower the yield of the given sample in moist condition the greater will be the effect. If the effect of drying obtained from different samples should be correlated with their yielding capacity in moist condition (per cent)<sup>6</sup> then the results of the experiments during the years 1916 and 1919 may be represented by table 2. It is evident that *the effect of drying increases as the yielding capacity of the soil in moist condition decreases*, or in other words, the less fertile soils respond better to drying.

TABLE 2  
*Effect of drying on yielding capacity of soils*

GROUPS ACCORDING TO THE MAGNITUDE OF EFFECT DUE TO DRYING	1916		1917	
	Average effect of drying	Average yielding capacity in moist condition	Average effect of drying	Average yielding capacity of soil in moist condition
<i>per cent</i>				
0-20	11	226	9	129
21-40	29	199	31	121
41-60	54	202	50	100
61-80			70	73
81-200	154	100	117	80

A closer examination of the cultural peculiarities of the soils which appeared to yield poorly in these experiments, allowed a characterization as soils potentially rich but capable of showing their fertility under special treatments only. These circumstances permit the conclusion that *drying is one of the powerful factors which help to transform the fertility elements of the soil from a potential to an active form.*

### III

How do different plants respond to the drying of the soil? How does the effect of drying change with the degree of drying of the soil sample? How does repeated drying act? How do different horizons of soil behave in relation to drying? The above data, which showed the general significance of the drying phenomena, brought forth these questions, a solution of which would throw some light upon the subject.

<sup>6</sup> For each series of plots of an experiment the yielding capacity of one sample was taken as 100 and the yielding capacity of all the other plots was expressed in percentage of that sample.

*Effect of drying on the yield of various plants*

As has been pointed out the above figures were obtained almost exclusively with millet, and only an insignificant number of experiments have been carried out with oats and buckwheat. Since different plants respond very differently to soil fertility it was necessary to determine to what extent the increase in fertility under the influence of drying appears as a general phenomenon for different plants. An experiment was begun in 1917 as follows. One sample of soil was taken from the surface layer of a field in a 3-year rotation and, after

TABLE 3  
*Relative yields of various plants showing effect of drying the soil*

PLANTS	YIELD ON MOIST SOIL	YIELD ON DRIED SOIL	AVERAGE EFFECT OF DRYING FOR DIFFERENT CROPS
Meadow plants.....			329
Gold hammer.....	100	568	
	100	291	
Legumes.....			35
Shabdar.....	100	138	
Red clover.....	100	137	
Vetch.....	100	135	
Lentils.....	100	134	
Alfalfa.....	100	131	
Field crops.....			28
Corn.....	100	137	
Oats.....	100	130	
Wheat (summer).....	100	130	
Millet.....	100	117	
Root, tuber and oil-yielding plants.....			11
Sunflower.....	100	116	
Beets.....	100	112	
Carrots.....	100	111	
Flax.....	100	109	
Potatoes.....	100	108	

a suitable preparation similar to that described above, was packed into pots which were then sown with 16 different plants, 4 pots being assigned for each plant—2 with moist soil and 2 with dried. The experiment gave the results shown in table 3.

All cultivated plants of the locality responded to drying with the following outstanding results: (a) The meadow plants showed an especially strong response, trebling and quadrupling the yield under the influence of drying. (b) Leguminous and field crops responded well to drying, the former more strongly than the latter. (c) Root, tuber and the oil-yielding plants showed a weak response, especially those that are cultivated during the growing season.

It is worth while to note that the greatest response has been obtained with plants which under natural conditions thrive in soils not subjected to the drying influence in tilling operations (meadows); the least response, on the contrary, was obtained with cultivated plants exposed to the greatest artificial drying caused by cultivation in the row.

*Degree of drying for beneficial effects*

The degree of drying under which the above effects have been obtained resulted, as mentioned, in 3 to 6 per cent moisture. The question arose

TABLE 4  
*Relative yielding capacity showing effect of degree of drying*

SOIL	MOISTURE AS COMPARED WITH ABSOLUTELY DRY SUBSTANCE	TOTAL WEIGHT	GRAIN
	<i>per cent</i>		
3-year system.....	32	100	100
	23	81	81
	13	94	91
	9	96	94
	6	131	127
	3	135	129
4 years of fallow.....	37	100	100
	25	75	73
	15	73	73
	9	91	83
	6	136	135
	3	144	151
Sod for 18 years.....	34	100	100
	23	83	88
	14	111	114
	7	217	229
	3	248	239

whether it is necessary to reach that degree of moisture and how in general does the fertility of the soil vary under different conditions of drying.

An experiment was set up in 1917 as follows. The sample of moist soil under experimentation was tested for its moisture content, then it was spread in thin layers on iron sheets and dried in the air to the weight which would correspond to the required moisture content. During the process of drying the soil was stirred almost continuously in order to avoid uneven drying of the upper layers. All samples described below were treated in this manner. Three samples of soil were taken for the investigation: (a) from a field under cultivation according to the old 3-year system, (b) from a field in fallow for 4 years, (c) from a field in sod for 18 years. The plant used in the experiments

was millet. The numbers in table 4 showing the greatest moisture content belong to the moist samples, which have not been subjected to drying, their respective yields being taken as 100.

It appears that a *positive influence of drying soils subjected to mechanical treatment, starts only at a 6 per cent moisture content, and for uncultivated land at 14 per cent. A decrease in yield is observed during the first stages of drying.*

#### *Effect of repeated drying on yield*

Repeated drying also was investigated. The soil sample was divided into five parts. The first part was left moist, and the others were subjected to drying. The second part was dried once, the third part after the first drying was moistened again with distilled water up to its original weight and then dried again; the fourth part was dried the same way 3 times; and the fifth part 4 times. All samples were then made up to the same moisture content and packed into pots. The plant used was millet. Three samples of soil were taken for this investigation: one from a field under the old 3-field system which has never been fertilized; another from the same kind of field but which

TABLE 5  
*Relative yielding capacity showing effect of repeated drying*

SOIL	TOTAL WEIGHT				
	Moist	Dried once	Dried twice	Dried 3 times	Dried 4 times
3-field system unmanured.....	100	145	137	154	156
3-field system manured.....	100	110	169	181	144
Uncultivated land.....	100	183	212	222	219

had been manured; the third from a field uncultivated for 18 years. The results are shown in table 5.

*Repeated drying increases fertility of the soil still further, and the maximum effect is apparently obtained with triple drying.*

#### *Effect of drying on the yield of different horizons*

An experiment to ascertain the response to drying of the different horizons of the soil was set up in 1917 with three soil samples; from a field under the old 3-field system which has never been manured; from a plot 4 years in fallow; from a field uncultivated for 18 years. In each one of these fields two borings were made to the depth of 1 meter and layers of soil were taken from the walls of these holes at 0 to 20, 20 to 40, 40 to 60, and 60 to 80 cm. In the four borings on the plot of the 3-field system and in the uncultivated field horizon, A ended at 42 to 45 cm; and horizon C began at 1 meter; in two borings on the fallowed field, horizon A ended at 20 cm., and horizon C began at 63 cm. Layers of soil from duplicate borings were combined and passed through a sieve. Half the combined sample was dried; then the packing of wet and dry

soil was carried out according to the methods described. The plant used was millet. The results obtained are shown in table 6. The yields from the dried samples are expressed in the percentage of yield from the corresponding moist samples.

*The maximum effect of drying was exhibited by the two middle horizons, 20 to 40 and 40 to 60 cm.* It decreased in the upper layer (0 to 20 cm.) as well as in the lower (60 to 80 cm.). This phenomenon is undoubtedly connected with the periodic drying through the cultivation of the upper layer; the decrease in humus content and in the number of microorganisms which always occur in regions of transition to the subsoil, is responsible for the phenomenon in the lower layer. This view is supported by the absence in the case of the sample from the fallow field, where the horizon 60 to 80 cm. was already the subsoil. It is worth while to pay special attention to the great difference between the cultivated and the uncultivated soils, although the borings from which the samples were taken were not more than 10 sajens<sup>7</sup> apart. Apparently the uncultivated land differed greatly from the cultivated land as far as the distribution of organic substances and microflora is concerned.

TABLE 6  
*Effect of drying on yield of different horizons*  
(Per cent of yield of moist samples)

HORIZONS	0 TO 20 CM.	20 TO 40 CM.	40 TO 60 CM.	60 TO 80 CM.
Field under the old 3-field system.....	141	288	259	140
Field under 4 years' fallow.....	176	314	273	96
Uncultivated land.....	283	374	374	282

#### IV

The tremendous effect of drying found in all described experiments apparently must be accompanied by some appreciable changes in the composition of the dried soil. In order to determine the nature of the changes and their significance, analyses of three samples of soil in moist and dried condition have been carried out, as follows:

	cm.
Cultivated land, horizon.....	0-20
Cultivated land, horizon.....	20-40
Uncultivated land, horizon.....	0-20

Soil extracts were prepared and analyses made for the total minerals, organic substances, nitrogen and  $P_2O_5$  in the extract. The solvents used were water, 2 per cent acetic acid, 2 per cent citric acid, 0.5 per cent oxalic acid, 0.5 per cent nitric acid, and 1 per cent nitric acid. Besides, the total amount of ammonia, amides and bacterial numbers in the soil were determined. The extracts were obtained by shaking the soil for  $\frac{1}{2}$  hour with five times its amount of the

<sup>7</sup> 1 sajen equals 7 feet.

solvent. The amount of water contained in the soil was taken into consideration in calculating the strength of the solvent.

Determinations of the mineral substances were carried out by evaporating a certain amount of the sample, igniting and treating the residue with  $\text{HNO}_3$ .

Determinations of the organic substances were carried out by the permanganate method modified in the author's laboratory. The total nitrogen was determined (according to Kjeldahl) by digesting a certain amount of the extract after acidifying the sample and evaporating almost to dryness in the Kjeldahl flask on a water bath.

The organic matter having been removed with  $\text{KMnO}_4$ , total phosphorus was determined by a colorimetric method worked out in the author's laboratory.

Ammonia nitrogen was determined by Schloesing's method modified in the author's laboratory, extracting the soil with oxalic acid and distilling the extract with  $\text{MgO}$ .

Amide nitrogen was determined by *Bussen's* method, by distilling a certain weight of soil with  $\text{MgO}$ . Finally the number of bacteria was determined by the ordinary bacteriological methods with Brown's albumin agar as the nutrient media.

The results obtained are compiled in table 7.

*The table shows that the analyses do indicate large chemical changes taking place in the soil upon drying.*

It is necessary to note here: (a) the small change in the solubility of mineral substances, (b) large increase in the solubility of organic substances, (c) large increase in the two fundamental nutrient substances, nitrogen and phosphorous, (d) an extremely large increase in the soil of ammonia nitrogen, (e) a considerable increase in the amide nitrogen, and (f) a sharp decrease in the number of microorganisms.

All the changes are similar to those which take place in the soil under the influence of partial sterilization with antiseptics or by heating, a phenomenon observed earlier by various authors. Therefore, according to the character of the chemical changes, we are obliged to consider drying of soil as its partial sterilization.

Let us pay some attention to some of the relationships resulting from the data. (a) The weaker the solvent taken for extraction, the more pronounced is the difference between the moist and dried soil; the 1.0 per cent nitric acid does not in many cases make any more difference. (b) In regard to chemical analysis, the soils correspond in order to the yielding capacity in the pots. (c) *the analyses of a soil for its fertility cannot be made on a dried sample; this probably explains the failure of such analyses.*

## V

The similarity in the chemical changes taking place in the soil under the influence of drying, with those after partial sterilization, induced the author to determine the influence of partial sterilization on the soil used in the experiments on drying.

TABLE 7  
Composition of soil extracts with various solvents  
(Per kilogram of dry soil)

		CULTIVATED, 0 TO 20 CM.		CULTIVATED, 20 TO 40 CM.		UNCULTIVATED, 0 TO 20 CM.	
		Moist	Dried	Moist	Dried	Moist	Dried
		mgm.	mgm.	mgm.	mgm.	mgm.	mgm.
Total mineral substances	Water.....	235	200	110	175	165	170
	Acetic acid.....	3,260	3,650	2,860	3,470	3,080	3,760
	Citric acid.....			6,230	6,990		
	Oxalic acid.....	2,620	2,520	2,870	3,220	2,140	1,670
	Nitric acid, 0.5 per cent.....			8,940	10,050		
	Nitric acid, 1.0 per cent.....	14,090	14,160	13,250	12,640	13,040	13,340
Total organic substances	Water.....	36	120	0	444	51	301
	Nitric acid, 0.5 per cent.....			650	1,237		
	Nitric acid, 1.0 per cent.....	460	596	1,172	1,698	957	1,086
Total nitrogen	Water.....	14.5	16.7	8.5	38.1	7.2	23.3
	Acetic acid.....	34.2	36.3	10.6	51.0	17.3	24.8
	Citric acid.....			17.5	70.5		
	Oxalic acid.....	50.1	56.7	25.9	64.3	18.8	35.4
Total P <sub>2</sub> O <sub>5</sub>	Water.....	1.2	2.5	0.7	4.7	0.6	7.2
	Acetic acid.....	2.6	4.6	3.0	7.0	2.3	6.0
	Oxalic acid.....	59.1	57.9	71.6	73.7	37.9	37.7
	Nitric acid, 0.5 per cent.....			16.6	19.1		
	Nitric acid, 1.0 per cent.....	39.7	41.1	41.4	41.9	22.5	23.4
Ammonia nitrogen.....		0	14.300	1.000	14.600	0.210	24.300
Amide nitrogen.....		61.400	93.900	38.500	64.000	75.800	88.500
Number of bacteria (millions per gram).....		1.650	0.380	0.920	0.201	1.955	0.702

TABLE 8  
Effect of sterilization on crop yield

	LOW SMALL ZINC POTS		HIGH SMALL GLASS POTS	
	Unsterilized	Sterilized	Unsterilized	Sterilized
Total weight of yield.....	100	248	100	411
Grain.....	100	254	100	700

In 1919 the author tried to establish the influence of steam sterilization in an autoclave at 2 atmospheres' pressure for 4 hours. A soil from one of the rotation plots of the experiment station fields, after sterilization, was packed into pots and sown with spring wheat.

The influence of sterilization was very great, the increases obtained being the greatest known in literature. The black soil of the experimental station

may be characterized, therefore, as one that is very sensitive to such treatments.

The influence of somewhat weaker reagents was tested in 1917; the treatments consisted in heating to different temperatures at ordinary pressure, and the use of antiseptics. The soil was taken from the field in the old 3-field system which had not received any fertilizers. The heating was performed in receptacles on a water bath soon after the sample with its natural moisture content was taken; the period of heating was 7 hours from the time the soil assumed the required temperature. The treatment with antiseptics was carried out in glass flasks filled to half their capacity with soil. Into the flasks wire spirals filled with cotton and wrapped with cloth were placed, the cotton being soaked with the antiseptic; the soil was subjected to the fumes of the antiseptic for 3 days, during which time it was frequently mixed by shaking and rolling. Chloroform, toluol and formalin were the antiseptics used. At the end of the period, the soil was placed on iron sheets for ventilation, precautions being taken against drying; the ventilation was carried out in a dark

TABLE 9  
*Relative yields showing the effect of heating and antiseptics on the yielding capacity of soils*

	USUAL TEMPERATURE		HEATING							ANTISEPTICS		
	Moist	Dried	35°C.	45°C.	55°C.	65°C.	75°C.	85°C.	95°C.	Chloroform	Toluol	Formalin
Total weight.....	100	117	93	121	135	158	142	150	180	170	164	97
Grain.....	100	107	86	115	126	147	119	128	161	165	142	79

cool place; the weight of water lost by evaporation was compensated by spraying the soil with distilled water. It took 3 days to removed the chloroform or toluol; and, more than a week to remove the formalin (even then the odor could be detected). The soils were packed into pots with ordinary precautions, and sown with millet.

The experiment (table 9) showed, that *antiseptics or moderate heating influenced the fertility of the soil very greatly, exceeding in that respect the influence of drying.*

A very interesting phenomenon represents the disproportionately high increase in yield at 65°C., and its decrease at 75°. This is observed to be in perfect analogy with the course of evolution of CO<sub>2</sub> in the heating of soil as established by Dehérain and Demoussy (1). They obtained an increase in the evolution of CO<sub>2</sub> from 45° to 65°, a decrease from 65° to 80° and another rapid increase above 80°. This may be explained by considering the combined action of the biological and chemical oxidation at low temperatures, the disappearance of the biological factor at temperatures above 60°, and an increased chemical decomposition at temperatures above 80°.

## VI

Whether the drying of soil is carried out under artificial conditions or takes place under natural conditions in the surface horizon of the field, the phenomenon of drying is a result of several reciprocally related factors. Outside of the removal of water by evaporation, other things take place, such as: an increased aeration of the soil and subsequently the influence of oxygen; the heating caused by the sun rays which, in the case of the black-soils, reaches very high temperatures; the effect of the light itself which is capable of influencing the biological processes of the soil as well as its chemistry.

The question therefore arises, as to which of the four factors instrumental in the drying of soils should the main rôle of increasing the soil fertility be ascribed; the removal of water, the increased aeration, heating, or the influence of light?

TABLE 10  
*Influence of aeration in connection with drying of soil, 1917*

	CULTIVATED LAND, UNFERTILIZED			
	Ordinary moist	Dried	Spread out and watered	Anaerobic
Total weight.....	100	117	95	84
Grain.....	100	107	95	83

TABLE 11  
*Influence of aeration and various degrees of moisture in connection with drying*

1918, TOTAL WEIGHT	ORDINARY MOIST	DRIED	AERATION IN DARKNESS	ANAEROBIC
Cultivated but unfertilized.....	100	145	129	93
Cultivated and manured.....	100	110	85	73
Uncultivated.....	100	183	125	108

Two experiments during 1917 and 1918 were intended to throw some light on the influence of aeration. The soil samples, taken from the surface horizon of the different plots, after having been passed through a sieve and well mixed, were divided into equal parts and subjected to the following treatments. One part was placed in glass flasks, stoppered and kept in darkness in an anaerobic condition without excess of oxygen; the second part was spread out in a thin layer on an iron sheet, placed in a dark barn and kept at a constant moisture content; the third part was spread in thin layers on an iron sheet, placed in the green house and exposed to drying; the fourth was left in the barn in a pile. The results showing the yield in relative numbers are given in tables 10 and 11.

Anaerobic preservation in all cases except in the uncultivated land gave a decrease in yield; aeration in darkness in two cases produced small decreases

in yield, and in two others small increases; drying in sunlight, that is to say, combined action of dehydration and aeration caused by the heat and light, gave in all cases considerably larger yields than all other preliminary treatments. In that way it has been established, *that aeration by itself, even if it does raise the yield, does it to an insignificant extent; and in the same way exclusion of oxygen decreases the yield insignificantly. A large effect is produced by drying in sunlight only, that is to say, the combined action of dehydration due to the sun rays, the light itself and aeration.*

In 1921 the author attempted to separate out completely each of the named factors.

The scheme was as follows:

- I. Maintaining anaerobic conditions without drying.
- II. Maintaining aerobic conditions without drying.
- III. Maintaining aerobic conditions with drying.

In each series, the preparation of the soil was carried out:

- (a) at ordinary temperatures in darkness.
- (b) at raised temperature in darkness.
- (c) in reflected light.
- (d) in the sunlight.

The setting up was carried out in the following way.

Anaerobiosis was attained by placing soil in glass carboys of 5 poods capacity. These were stoppered with corks and sealed with Mendeleeff's sealing wax. Some of the carboys were then placed in an absolutely dark place at ordinary room temperature; a second group, in a dehydrating oven, kept in darkness and heated to a certain temperature; a third, in a greenhouse with glass roof; a fourth, in the same greenhouse under immediate sun rays.

Aerobic conditions without drying were attained by spreading the soil in a thin layer on iron sheets, with continuous stirring and watering from a spray thus keeping it at constant weight. As far as the temperature and light are concerned the conditions were the same as in the preceding case.

Aerobic conditions with drying were attained in the same way as the preceding; beside the moistened soil was a sheet with unmoistened soil.

In the course of the experiment the sun was very hot and the differences were therefore especially marked.

The temperatures of the places of storage were as follows:

The dehydrating oven.....	38-42°C.
The greenhouse in the sun.....	29°C.
The greenhouse in dim light.....	25°C.
The ordinary room temperature.....	20°C.

The length of treatment under different conditions was naturally very different and is indicated in the following figures:

	<i>days</i>
Anaerobic in sunlight.....	10
Anaerobic in reflected light.....	10
Anaerobic in darkness at ordinary temperature.....	10
Anaerobic in darkness at rising temperature.....	10
Aerobic in sunlight.....	2
Aerobic in reflected light.....	4
Aerobic in darkness at ordinary temperature.....	10
Aerobic in darkness at rising temperature.....	10

Two samples of soil were taken, layer 20 to 40 cm. from an old cultivated land which has never been manured, and layer 0 to 20 cm. from uncultivated land. At the end of the treatment the soil was packed into pots and sown with millet. Table 12 shows the data of yields:

In order to single out the various interesting factors which these data afford, the conclusions in tables 13 and 14 may be drawn.

The influence of oxygen on uncultivated soils in all cases was found to be negative, on cultivated soils in two cases negative and in one case positive;<sup>8</sup> on the average, in the case of the uncultivated soil, 21.4 per cent, and for cultivated soil, 4.4 per cent. In other words, oxygen either has no effect or its effect is negative.

The removal of the water caused a large increase in yield on the uncultivated as well as on the cultivated soil.

The influence of raised temperatures (table 15) was revealed on both soils in a large increase in yielding capacity, for uncultivated land in 154 per cent, for cultivated in 60.9 per cent.<sup>9</sup>

Since the influence of light is always complicated by the simultaneous increase in temperature, this appeared to be the most difficult question for solution. The three gradations of light used in the experiment are accompanied by the following differences in temperature: darkness, 20°; reflected light, 25°; sunlight, 29°. Because of that, in tables 16 and 17 besides the direct relationships of the different gradations of light, the data with the increase due to temperature are given, the latter having been calculated arbitrarily according to the above figures of the influence of the raised temperature: for the fallowed land 3.0 per cent per 1° ( $60.9:20 = 3^\circ$ ), for uncultivated land 7.7 per cent per 1° ( $154:20 = 7.7$ ).

From tables 16 and 17 it is evident that the effect of light on cultivated land has been clearly negative; even without corrections for the temperature in all of the averages, in most of the individual cases the results obtained have been negative. For uncultivated soil increases in yield have been obtained without corrections for temperature, which is easily explained by the fact that this soil is highly reactive to heating. It is actually true that when the corrections for

<sup>8</sup> The fourth pot was discarded, for since the duplicate pot of the series, "darkness at ordinary temperature anaerobic," was broken, the remaining gave a foreseen decreased yield.

<sup>9</sup> The increase of 200 per cent was disregarded, because in calculating, the same doubtful figure 0.8 as above was used.

TABLE 12

*Total weight of yield showing the effect of light at various temperatures in connection with drying of soils*

	ANAEROBIC WITHOUT DRYING				AEROBIC WITHOUT DRYING				AEROBIC WITH DRYING			
	Darkness at ordinary temperature	Darkness with temperature raised	Reflected light	Sunlight	Darkness at ordinary temperature	Darkness with temperature raised	Reflected light	Sunlight	Darkness at ordinary temperature	Darkness with temperature raised	Reflected light	Sunlight
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
Old cultivated land.....	(0.8)	2.4	1.4	1.2	1.5	2.2	1.1	1.4	2.8	4.9	2.9	2.1
Uncultivated land.....	1.5	4.3	1.4	2.0	1.4	3.0	1.0	1.6	1.8	4.7	2.4	2.0

TABLE 13

*The influence of oxygen*

SOIL	CULTIVATED				UNCULTIVATED			
	Total weight		Increase due to oxygen		Total weight		Increase due to oxygen	
	Without oxygen	With oxygen			Without oxygen	With oxygen		
	gm.	gm.	gm.	per cent	gm.	gm.	gm.	per cent
Darkness at ordinary temperature.....	0.8	1.5	(+0.7)	(+87.0)	1.5	1.4	-0.1	-6.7
Darkness with temperature raised.....	2.4	2.2	0.2	-8.4	4.3	3.0	-1.3	-30.2
Reflected light.....	1.4	1.1	-0.3	-21.4	1.4	1.0	-0.4	-28.6
Sunlight.....	1.2	1.4	+0.2	+16.7	2.0	1.6	-0.4	-20.0
Average.....				-4.4				-21.4

TABLE 14

*The influence of the removal of water*

	CULTIVATED				UNCULTIVATED			
	Total weight		Increase due to drying		Total weight		Increase due to drying	
	Without drying	With drying			Without drying	With drying		
	gm.	gm.	gm.	per cent	gm.	gm.	gm.	per cent
Darkness at ordinary temperature.....	1.5	2.8	+1.3	+86.9	1.4	1.8	+0.4	+28.5
Darkness with temperature raised.....	2.2	4.9	+2.7	+123.5	3.0	4.7	+1.7	+56.7
In reflected light.....	1.1	2.9	+1.8	+164.0	1.0	2.4	+1.4	+140.0
In sunlight.....	1.4	2.1	+0.7	+50.0	1.6	2.0	+0.4	+25.0
Average.....				+105.9				+62.5

temperature are introduced the increases in yield are changed into decreases. One might think that light in itself does not play any rôle in the increased fertility in soil drying and apparently has even a negative effect.

TABLE 15  
*The influence of rise in temperature*

	CULTIVATED				UNCULTIVATED			
	Total weight		Increase due to temperature		Total weight		Increase due to temperature	
	Ordinary temperature, 20°	Raised temperature, 40°			Ordinary temperature, 20°	Raised temperature, 40°		
	gm.	gm.	gm.	per cent	gm.	gm.	gm.	per cent
Anaerobic without drying.....	(0.8)	2.4	(+1.6)	(+200.0)	1.5	4.3	+2.8	+186.5
Aerobic without drying.....	1.5	2.2	+0.7	+46.7	1.4	3.0	+1.6	+114.0
Aerobic with drying.....	2.8	4.9	+2.1	+75.1	1.8	4.7	+2.9	+161.5
Average.....				+60.9				+154.0

TABLE 16  
*The fundamental data*

	INCREASE					
	Reflected light, temperature, 25°; darkness at ordinary temperature, 20°		Sunlight, temperature, 29°; reflected light, temperature, 25°		Sunlight, temperature, 29°; darkness at ordinary temperature, 20°	
	gm.	per cent	gm.	per cent	gm.	per cent
Cultivated						
Anaerobic without drying.....	(+0.6)	(+75.0)	-0.2	-14.2	(+0.4)	(+50)
Aerobic without drying.....	-0.4	-26.7	+0.3	+27.2	-0.1	-6.7
Aerobic with drying.....	+0.1	+8.6	-0.8	-27.6	-0.7	-25.0
Average.....		-7.7		-4.9		15.8
Uncultivated						
Anaerobic without drying.....	-0.1	-6.7	+0.6	+43.0	+0.5	+33.3
Aerobic without drying.....	-0.7	-50.0	+0.6	+60.0	+0.2	+14.3
Aerobic with drying.....	+0.6	+33.3	-0.4	-16.7	+0.2	+11.1
Average.....		-7.8		+28.8		+19.6

A summary of all the data on the effect of the individual factors in the drying of soil is presented in table 18.

It may be that in all cases the removal of the water and the increase in temperature give a positive effect; and the oxidation with oxygen, with the aid and the influence of light, negative. In one case, the removal of the water acts

more strongly than the increase in temperature; in the other the action of temperature is stronger than the increase in dehydration.

Therefore we can say that the change in fertility of the soil by drying is conditioned by the removal of water, by evaporation, and by the heating of the soil by the rays of the sun.

TABLE 17

*Summary of the effect of light in connection with drying of soils—average of the results*

	CULTIVATED			UNCULTIVATED		
	Re- flected light, dark- ness	Sun- light, re- flected light	Sun- light, dark- ness	Re- flected light, dark- ness	Sun- light, re- flected light	Sun- light, dark- ness
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Without correction for temperature.....	-7.7	-4.9	-15.8	-7.8	-28.8	-19.6
With correction for temperature.....	-22.7	-16.9	-42.8	-46.3	-0.2	-49.7
Average { Without corrections.....	-9.4			-13.5		
{ With corrections.....	-27.4			-32.7		

TABLE 18

*The increase in yield under the influence of the individual factors*

	CULTIVATED					UNCULTIVATED				
	Dark- ness at ordinary tem- perature	Darkness with temper- ature raised	Reflected light	Sun- light	Average	Dark- ness at ordinary tem- perature	Darkness with temper- ature raised	Reflected light	Sun- light	Averages
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Oxygen		-8.4	-21.4	+16.7	-4.4	-6.7	-30.2	-28.6	-20.0	-21.4
Water	+86.9	+128.5	+164.0	+50.0	+105.9	+28.5	+56.7	+140.0	+25.0	+62.5
Tempera- ture		+40.7 +75.1			+60.9		+186.5 +114.0 +161.5			+154.0
Light			+22.7	-16.9 -42.8	-27.4			-46.3	-0.2 -43.7	-32.7

## VII

All of the above data have been obtained under artificial conditions; the soil sample which was taken from the field was dried in the air and its fertility was determined by means of pot experiments. Does the above-named process take place under natural conditions and what are the results accompanying it? An approach to this problem was made in three ways.

First, observations were taken on the moisture content of the surface layers of the soil under natural conditions. Samples were taken from the experiment station fields in the following way. From each place dry lumps of soil were collected and then the wet ones lying next to them or right underneath; their moisture content was then determined. Data on the collected material is compiled in table 19.

The data which have been taken as representative from many others show, that *the drying under natural field conditions may reach a very high degree: sufficient, as we have seen, to cause large increases in soil fertility.* It takes place under the influence of the mechanical treatment of the soil and comes on very soon after the breaking up of the capillary tubes.

Besides investigating these qualitative effects characteristic of the natural drying of the soil, an attempt was made to approach the question from the quantitative side by determining the thickness of the layer which assumes the necessary degree of dryness. For this purpose special three-grained augers with one movable side were used. Each auger was inserted into the soil until it penetrated the moist soil sufficiently deep; then it was removed together with the soil; the movable side being opened, the exposed inside of the auger showed the profile of the soil with the border line between dry and moist parts; the moisture content of these parts was determined.

The determinations were made on April 24, three weeks after the field work has been started. The results are shown in table 20.

*In this way, after 3 weeks of the vegetation period, the surface layer of the soil, averaging 4 cm. deep (one-third of the ordinary plowed layer), assumes the moisture content at which the increase in fertility of the soil due to drying becomes possible.*

Then an attempt was made to compare the fertility of the naturally dried lumps produced in the field with the fertility of the surrounding moist soil. From the surface of the plot some of the dry lumps were collected at the time the surrounding moist soil was taken. Both of the soil samples were made up to the same moisture content, packed into pots and sown with millet.

The soil samples were taken at three different periods:

1. On April 7 a soil sample was taken from an April fallowed plot, plowed on April 5 to the depth of 4 vershoks and harrowed on April 6.

The moisture content of the dry soil was 8.5 per cent, and of the moist soil 33.6 per cent. Soon after the appearance of the millet seedlings it became evident that the better growth was in the pots with dry soil. The difference increased steadily, reaching its culmination during the stage of heading out. During the subsequent growth period the differences began to disappear and the yields were the same according to the total weight, with only a slight increase in grain on the dried soil.

2. On April 27 samples were taken from a plot of an early autumn fallow, plowed in the autumn on August 20 to the depth of 4 vershoks and harrowed on April 5. The only rain from the beginning of the spring was on April 13

TABLE 19  
Moisture content\* of various lumps of soil under natural conditions

PLACE OF SAMPLING	DATE OF SAMPLING	KIND OF SAMPLE	MOISTURE CONTENT OF TOTAL DRY SUBSTANCE <i>per cent</i>	REMARKS
Fallow first working in April	April 6	Dry lumps	11.00	The field was ploughed 4 vershkos deep on April 5; harrowed April 6, sampling was done several hours on a day after that; clear sunny day.
		Moist lumps	32.19	
	April 7	Dry lumps	8.55	Samples from the same field after 12 days; the surface of the field is covered with a layer of large lumps, under which is the moist soil.
		Moist lumps	34.77	
Fallow first working in April	April 18	Dry lumps	3.72	The field was not plowed in the fall; in the spring it was flooded; from the surface was separated out a thin crust, under which were the moist layers.
		Dry large lumps	4.56	
		Moist soil	30.19	The field was plowed in the fall, in August; and was harrowed in the spring.
	April 18	Dry surface crust	4.35	
Field in potatoes the previous year		Moist layer beneath surface crust larger	18.77	The field was plowed in the spring, harrowed and sowed with oats; at sampling the oats were coming up.
		Moist layer somewhat deeper	24.38	
Early fall fallow	April 18	Dry lumps	4.11	A day before the clover was plowed under.
		Moist soil	31.53	
Oat field	April 18	Dry lumps	3.74	
		Moist soil	35.56	
First working of a clover field	April 18	Dry lumps	5.51	
		Moist soil	38.37	

Early fall fallow	June 9	{ Dry lumps Moist soil	4.1 18.68	From the plot under the same name from which a sample was taken on April 18; during the period several inches of rainfall came down.
Early fall fallow	June 18	{ Dry lumps Moist soil	3.47 15.05	Same as above with more rain in the meantime.
Early fall fallow	June 22	{ Dry lumps Moist soil	2.44 25.82	Same as above with more rain.

\* The averages of duplicate determinations are given.

to the depth of 0.2 mm. The plot was covered with a layer of dry soil  $1\frac{1}{2}$  cm. thick from which the dry samples were taken. The moist soil lying immediately underneath was taken to the same depth. The moisture content of the dry soil was 7.7 per cent, of the moist—30.28 per cent. The increase in growth on the dry soil was evident from the very beginning of the vegetative period, and gradually increased until the end of the growth period. As a result, the total yield and the size of the grain were much larger on the dry soil.

3. The third sample was taken from the same plot on June 23. Since the preceding sampling the field had been subjected once to harrowing. The drought which existed during April changed into a period of rainy weather

TABLE 20  
*Moisture content of various layers and depth of latter*

PLACE OF SAMPLING	KIND OF SAMPLE	MOISTURE CONTENT OF TOTAL DRY SUBSTANCE	DEPTH OF THE DRY LAYER	REMARKS
		<i>per cent</i>	<i>cm.</i>	
April fallowing	Dry	12.40	3.0	The field was plowed to a depth of four vershoks on April 5 and harrowed on April 6
	Moist	25.44		
Early autumn fallowing	Dry	8.99	3.5	The field was plowed in the fall, August 20, to a depth of 4 vershoks and harrowed in the spring
	Moist	31.55		
Late autumn fallowing	Dry	7.03	4.0	The field was plowed in the fall, October 1, to a depth of four vershoks and harrowed in the spring
	Moist	31.70		
Oat field	Dry	8.23	4.0	Plowed and harrowed in the spring and sown to oats April 10
	Moist	29.40		
Oat field	Dry	7.20	1.5	Plowed to a depth of four vershoks in the fall, harrowed in the spring and sown to oats on April 12
	Moist	42.03		

from May 10 to 24, the total rainfall being 104 mm. A comparatively dry period followed from May 25 to June 9 (only 10.8 mm. rainfall), then 4 days with a large precipitation (27.8 mm.), and again a dry period until the time of sampling. The dry layer at the time of sampling was  $\frac{3}{4}$  vershok, and the moist soil was taken right underneath. The moisture content of the dry soil was 3.67 per cent, and of the moist, 25.32 per cent. In the first stage of vegetation a marked superiority of the pots with the dry soil over the pots with the moist soil was observed. Later on it began to disappear and yield-data showed the superiority of the dry soil in the total weight of the plants only. The yield data of all the three experiments are given in table 21.

In all three cases a measure was thus obtained by pot experiments of the change in soil fertility under the influence of natural drying of the soil surface

TABLE 21  
*Relative yields on dry and moist samples of soils*

PLACE OF SAMPLING	DATE OF SAMPLING	CONDITION OF THE SOIL	MOISTURE CONTENT AT THE TIME OF TAKING	RELATION BETWEEN DRY- AND MOIST-SOIL YIELDS		
				Total weight	Grain	Straw
			<i>per cent</i>			
April following.....	April 7	Moist	33.6	100	100	100
		Dry	8.5	100	113	88
Early autumn following.....	April 24	Moist	30.28	100	100	100
		Dry	7.7	196	197	176
Early autumn following.....	June	Moist	25.32	100	100	100
		Dry	3.67	121	94	142

TABLE 22  
*Relative yields on dried and moist plots in field experiments*

YEAR	PLANT	SOIL	PLOT	RELATIONSHIP BETWEEN YIELDS ON MOIST AND DRIED SOILS		
				Total weight	Grain	Straw
1916	Millet	Unfertilized	Moist	100	100	100
			Dried	129	116	131
	Buckwheat	Unfertilized	Moist	100	100	100
			Dried	114	111	116
1917	Oats	Unfertilized	Moist	100	100	100
			Dried	116	134	108
		Manured	Moist	100	100	100
			Dried	123	120	126
	Millet	Unfertilized	Moist	100	100	100
			Dried	105	112	99
		Manured	Moist	100	100	100
			Dried	113	109	116
		Uncultivated	Moist	100	100	100
			Dried	119	121	117

layer during the vegetative period. The change in fertility was expressed by different degrees of intensity, sometimes increasing the growth only in its early stages, but sometimes bringing about a large increase in the yield of grain

and straw. The differences observed may be attributed to many causes, for example, the leaching out by the rain of the compounds formed in the dried soil layer.

Finally an attempt was made to carry out an actual field experiment of drying. With that purpose plots of 1 by 4 meters were staked out in the field and the plowed layer to the depth of 3 vershoks was removed and dried on iron sheets in the field. After the drying the soil was made up to its original moisture content and replaced. On the control plot the same removal and replacing of the plowed layer was carried out. It was possible to bring the dried soil to a moisture content of 6 to 7 per cent; that of the moist soil was most of the time about 30 per cent. The plots were then sown with different plants and the yields observed. The results of the outlined experiments are given in table 22.

These results show that *the increase in fertility of the soil under the influence of drying may be obtained not only with plants grown under artificial conditions (pot experiments), but also under natural conditions in the field.* Besides, just as in pot experiments, the uncultivated manured soil responds more strongly to drying than the unfertilized soil. The magnitude of the increase in yield in the described field experiments expressed itself in smaller figures than in most of the pot experiments. This phenomenon may be explained by the fact that in the field experiments, the natural drying of the soil during the period of growth, which took place on the dried soils as well as on the moist plots, could not be excluded; consequently the results of the experiment showed the difference in intensity of drying in both cases.

Summarizing the data in relation to the applicability of the raising of soil fertility by means of drying under natural conditions, the following may be said: (a) that the surface layers of the soil through the natural processes of drying are able to obtain the necessary moisture content to raise its fertility; (b) that according to pot experiments the soils dried in such a manner appeared to be more fertile than those that remained moist; and (c) that according to field experiments the naturally dried surface layer of the field plots increases its fertility.

From this we may draw, with a large degree of certainty, the final conclusion, *that the process of drying is a powerful factor determining to a large extent the fertility of the soil under natural conditions.* It is probably playing an important, until now unknown, rôle in all the processes of increasing the soil fertility obtained by means of mechanical cultivation of soil.

## VIII

Let us pass now to a more detailed consideration of this conclusion. It has always been considered that the plowed layer of the soil is the place where the plants obtain their nutrients. Although the roots of the plants spread out to a considerable depth, most of them are located here. It is this layer that is manured; in it primarily go on the processes of fermentation which produce

the available nitrogenous substances; in it also takes place the decomposition of humus, on which depends the whole life activity of the soil and as a result, the nutrition of the plants. This surface layer, therefore, is the mysterious laboratory in which are created the main conditions of high or low yield. Large moisture content creating favorable conditions for the activity of the micro-organisms, and good aeration guaranteeing a sufficient supply of oxygen, are considered as the main conditions determining the cultural condition of the soil. Based on these, it was natural to suppose that the maximum fertility of the soil surface layer is located at a little distance below its surface; there the required moisture, lacking in the upper layers, is found together with an abundant supply of oxygen which is lacking in the lower layers. *The center of fertility, therefore, has been thought to be a layer at a certain depth above or below which the fertility of the soil decreases; the very upper dried-out layer is only a necessary evil, for while this dry layer is inert from the standpoint of accumulation of fertility, it protects the layer beneath from drying out. This is the picture one gets, basing his conclusions on the predominating views on soil fertility.*

If the previously described supposition of drying the soil in connection with the natural formation of its fertility is correct, it is evident that the above picture of the distribution of the fertility must be changed. Aside from the important accumulation of the fertility through the activities of the micro-organisms, we also have increases in fertility of the surface layer due to the drying, which is contrary to widespread opinion that the fertility of this layer remains unchanged.

With sufficient importance ascribed to drying as a cause of increased fertility, one must find the maximum fertility in the upper layer and a gradual fall in the lower ones. In 1920 this problem was approached in the following way:

A plot 2 by 2 meters was laid out on a fallowed field. The surface layer to the depth of 20 cm. was removed from the whole plot, mixed well on iron sheets in order to remove all possible differences in fertility, and immediately replaced. The plot was left fallow; the only treatment it received was weeding by hand, and keeping a mellow surface by means of an iron rake. In order to protect the plot from rain special glass frames were placed one arshin<sup>10</sup> above the surface, insuring the proper ventilation, at night and on rainy days. Also, to avoid too great a drying the soil was watered with a watering can three times (May 3, 10, and 15) the amount of water each time corresponding to 7 mm. of precipitation. Samples of soil were taken from that plot every two weeks, in layers 0 to 5, 5 to 10, 10 to 15, 15 to 20, 20 to 30, 30 to 40, and 40 to 50 cm. A trench 50 cm. wide, the walls of which were reinforced with boards and covered with planks in order to diminish evaporation, was made along one of the sides of the plot for the purpose of sampling. Each sample of soil was sifted and packed into pots, with all the usual precautions to insure equalization of the moisture content of the different layers. Care was taken to prevent

<sup>10</sup> One arshin equals 28 inches.

drying during the determination of the moisture content of the samples. The pots were sown with millet.

Five series of pots were prepared from which it was possible to establish the relations of separate soil layers within each series. The absolute yields of separate series could not, of course, be compared, since they were set up at different times, but by changing them into relative figures it was possible to obtain a definite picture of the changes in fertility in individual layers in relation to each other within each series. Since the yield from the 40 to 50-cm. layer could be considered as constant during the whole experiment, by taking it as a unit it was possible to compare the series.

One may see that the fertility of each of the overlying layers increases as compared with the lower layer. Since the supposition that the fertility of the lower layer during fallowing decreases for some reason seems to be improbable,

TABLE 23

*The yield of separate layers of soil in the different series as compared with the yield of the layer 40 to 50 cm., taken as a unit*

DEPTH	APRIL 15	MAY 3	MAY 15	MAY 31	JUNE 12
cm.					
0-5	4.5	7.2	10.5	14.4	20.3
5-10	4.5	6.0	7.5	11.7	15.5
10-15	4.5	4.8	6.8	9.6	13.8
15-20	4.5	4.6	6.3	8.4	10.3
20-30	1.5	2.0	4.0	2.4	2.8
30-40	1.2	0.8	1.6	1.4	1.8
40-50	1.0	1.0	1.0	1.0	1.0

and since it seems more possible to assume the opposite, one must conclude that the fertility of all the soil layers increases during the vegetative period. The increase during these two months of fallowing reaches about three times the original condition of the soil. The first four horizons, as would be expected, are the most fertile; these layers embrace 0 to 20 cm. and represent the surface layer of the soil. The subsoil layers appeared to be markedly less fertile. The increase in soil fertility of the different layers is also unequal and for the 2 months of fallowing can be expressed in the following figures:

THE LAYER	THE INCREASE IN FERTILITY
cm.	
0-5	4.5 times
5-10	3.3 times
10-15	3.0 times
15-20	2.3 times
20-30	1.9 times
30-40	1.5 times
40-50	1.0 times

The upper horizon appears to be not only the most fertile one, but is also marked by the greatest increase in fertility, as compared with all other layers; this supports the assumption that the condition of its fertility is largely determined by the phenomena of its drying.<sup>11</sup> An attempt was then made to determine what takes place in the surface layer when it is turned under, the phenomenon being analogous to the plowed layer. For this purpose on one part of the above mentioned plot the surface soil was removed and immediately replaced but in the reverse order, that is to say, the layer 0 to 5 cm. was placed below and the layer 15 to 20 cm. above. The soil samples from the turned-over portion of the plot were taken together with those from the normal portion of the plot; they were packed into pots of the same size and were sown with millet on the same day. In such a way it was possible to compare both results completely. Taking as before the yield of the layer 40 to 50 cm. as a unit, the data in table 24 was obtained.

TABLE 24  
*Relative yield of separate layers of soil when placed in reverse order*

DEPTH OF LAYER cm.	MAY 15		MAY 31		JUNE 12	
	Unturned	Turned	Unturned	Turned	Unturned	Turned
0-5	10.5	6.3	14.4	8.2	20.3	23.1
5-10	7.5	6.8	11.7	12.1	15.5	22.2
10-15	6.8	7.5	9.6	12.7	13.8	15.6
15-20	6.3	10.5	8.4	6.3	10.3	9.6
20-30		4.0		2.4		2.8
30-40		1.6		1.4		1.8
40-50		1.0		1.0		1.0

In the turned-over surface layer, after 2 weeks one could note that the fertility of the exposed lower horizon increased; the fertility of the upper horizon plowed under decreased. After 2 more weeks the normal picture of the distribution of the fertility was established, expressed by a maximum fertility in the upper layer with a consequent diminution as the layer went deeper.

In such a way with artificial dislocation of horizons of the surface layer its fertility changes very abruptly and then *begins to return to its normal distribution which appears to be a maximum in the upper layer with consequent diminution lower down.*

<sup>11</sup> We deem it necessary to emphasize that both of the above described experiments on the distribution of soil fertility, are not to be considered as final proof in support of the exclusive effect of the phenomenon of drying of soil on the building of its fertility. These facts assist only in establishing more firmly the hypothesis; moreover, the only other possible explanation of the described phenomena may be the accumulation of nutritive compounds in the upper layers by means of the current of evaporating water. According to the material on hand which will be the subject of a later communication, this has a very limited influence.

## CONCLUSIONS

From what has been presented in this paper it may be assumed that there is ground for a serious consideration of the question of the rôle of drying soils. Especially is this important if one is to appreciate the methods for raising the soil fertility by means of mechanical treatment, or even for an appreciation of the systems of cropping. Is it not possible to look upon the methods of intertillage from this standpoint, instead of the accepted ideas of conserving moisture and increasing the aeration? May not the same question be raised in connection with the method of ridging potatoes? Is it not necessary to give a different interpretation to that system of intensive agriculture which includes special methods for drying the surface layers for the purpose of killing weeds and the conservation of moisture? Is not the drying of soil a key to a deeper appreciation of the system of sod or grass rotations, in which the soil on account of continuous tillage ceases to respond to mechanical treatment, but which attains its properties of raising the fertility under the influence of drying?

## FUNDAMENTAL PRINCIPLES

1. The drying of the soil to an air-dried condition in the open air at ordinary temperatures produces a large increase in the yielding capacity in the case of pot experiments.

2. The degree of increase in yielding capacity depends on the preceding cultural conditions of the soil. Especially responsive to drying appear to be the uncultivated soils, and those occupied by many years of grass culture; soils under continuous mechanical treatment respond less readily. Soils fertilized with stable manure or phosphates are more responsive than unfertilized soils. All other conditions being equal, the response of a soil to drying increases as the fertility decreases.

3. Different plants react differently to the drying of the soil. The greatest increase in yielding capacity is shown by meadow grasses, then come the field legumes, then the field grasses, and lastly the intertilled plants.

4. A positive influence of drying is evident only with cultivated soils reaching a 6 per cent moisture content, and with uncultivated soils reaching 14 per cent. With smaller degrees of drying not only no increase in fertility is observed but in most cases it is lowered.

5. Repeated drying of one and the same sample of soil with intermediate moistenings is accompanied by a further increase in the yielding capacity, and the maximum fertility is attained with triple drying.

6. The maximum effect of drying for deep black soil seems to be in the layers 20 to 40 and 40 to 60 cm. For surface soils (0 to 20 cm.) as well as for the layer lower than 60 cm., it is markedly less.

7. During the process of drying, important chemical changes take place in the soil, expressing themselves in a large increase in the solubility of organic substances, a large enrichment of the soil samples with nitrogen and phosphorous,

an extremely large increase in the soil of the ammonia nitrogen, a considerable increase of amide nitrogen and a sharp diminution in microorganisms.

8. All these changes are very similar to those taking place in the soil under the influence of low temperatures and antiseptics, as a consequence of which the drying of a soil may be considered as its partial sterilization.

9. Out of the four factors acting on the soil during its drying (removal of water through evaporation, increased influence of the oxygen, heating by sun rays and the effect of the light as such) the increase in fertility is dependent upon dehydration and temperature. Oxygen and light, on the contrary, cause a decrease in fertility.

10. The soil under natural conditions, with the aid of ordinary methods of mechanical cultivation, in the upper layer easily attains the moisture content necessary for the positive effect on fertility.

11. The soil which has naturally dried out in the field, according to pot experiments appears to be much more fertile than the dried soil lying nearby.

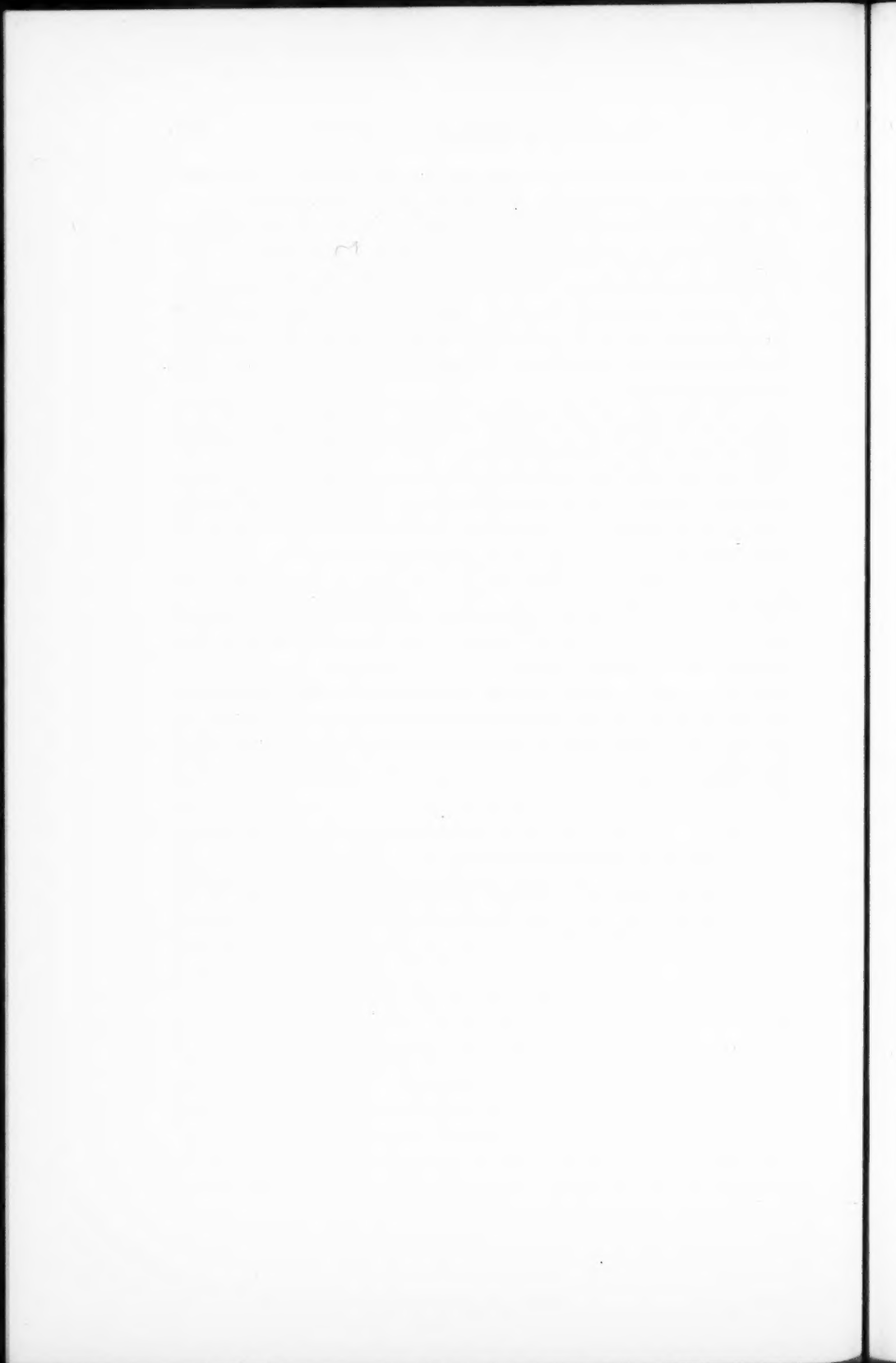
12. Artificial drying of the surface layer carried out in the field on several plots produced an increased growth of the plants grown on them.

13. The sum total of the above considerations leads to the conclusion that the process of drying is a factor controlling to a large extent the fertility of the soil, and as such must play an important rôle (until now unknown) in all processes of increasing the soil fertility, which is being achieved by the methods of mechanical cultivation of the soil.

14. As an indirect proof of this, the distribution of fertility in the surface soil and its changes during the vegetative period showed that the upper 5-cm. layer is the most fertile and also increases its fertility most rapidly; lower down the fertility of the soil decreases and the rate of increase during the vegetative period diminishes.

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## ALKALI STUDIES: I. TOLERANCE OF WHEAT FOR ALKALI IN IDAHO SOIL<sup>1</sup>

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In connection with extensive investigations dealing with the reclamation and prevention of alkali lands in Idaho, it was found advisable to conduct tolerance studies for various crops grown under Idaho soil and climatic conditions. This paper concerns the crop of wheat and is the first of a series reporting the data secured on these studies. Additional papers dealing with other crops will follow.

The necessity for tolerance studies of crops in various alkali regions is manifest, since tolerance of a crop for alkali depends upon many factors such as type of soil, type of salts and concentrations of the soil solution, and the location of the salts in the soil at various periods of the plant's growth. All such factors vary so greatly that the subject indeed becomes very complex.

It is patent from results in former alkali investigations reported in the literature that to establish definitely the effect of alkali concentrations on plant growth, two factors must be carefully considered; first, these studies should include not only added salt concentrations, but more important, the determination of the recoverable salt concentration in a soil. Headley, Curtis and Scofield (2) have clearly shown that the true measure of the effect of alkali salts on crop growth is determined by the amount of recoverable salts in the soil solution rather than the amount added. Secondly, tolerance studies, to be of greatest benefit, must be carried on during the entire growth cycle of the crop before definite and satisfactory conclusions can be drawn. These tolerance studies become more valuable when conducted on a sufficient amount of soil so that several crops can be grown on the same soil and data secured on the concentration of alkali salt recoverable from the soil after each crop. It is well known by investigators in alkali soil problems, that plants may germinate freely, grow for a short period, and then die because of alkali concentrations. The true criterion of tolerance of a crop for alkali is the capacity of a plant to grow to maturity and produce a crop, not merely the capacity to germinate and grow for a short period and die. That such conclusions are true will be shown when the data on all tolerance studies are presented.

A preliminary field alkali survey was conducted in Idaho with a view to ascertaining the predominating alkalies present in the soil. These results

<sup>1</sup> Published with the consent of the Director, as Research Paper No. 28 from the Idaho Agricultural Experiment Station.

will appear in published form at a later date. The predominating salts found in the soils analyzed were sodium carbonate, sodium chloride, and sodium sulphate, these salts occurring sometimes alone, but usually in various combinations. Our tolerance experiments, therefore, were conducted with these salts, and a characteristic soil was prepared to which these salts were added in definite concentrations both alone and in combinations, in order that exact information on the tolerance of crops would be obtained.

#### DETAILS OF THE EXPERIMENT

For the tolerance studies a car load of surface soil was secured from a comparatively alkali-free area on the Caldwell Substation Farm and shipped to Moscow. This soil is the bulk sample used in all the alkali concentrations in the tolerance studies. The soil is listed in the United States Soil Survey (3) as Boise Silt Loam Soil and is a characteristic soil for a large area. The mechanical analysis and moisture equivalent are given in table 1.

TABLE 1  
*Mechanical analysis and moisture equivalent of soil used*

	PER CENT
Clay.....	8.56
Silt.....	46.00
Very fine sand.....	22.31
Fine sand.....	18.65
Medium sand.....	1.30
Coarse sand.....	1.86
Fine gravel.....	0.93
Moisture equivalent.....	21.2

The entire car load was freed from lumps, thoroughly mixed, air dried and stored in a bin. Before making up each alkali series, a moisture determination was made on the soil in order that the concentrations of added alkali could be made upon the basis of the moisture-free soil.

In all tolerance studies, the method of preparing the soil and general details of manipulation are similar, hence a complete description will be given in this first publication. The alkali salts used were chemically pure anhydrous sodium carbonate, sodium chloride and sodium sulphate.

#### PREPARATION OF THE ARTIFICIAL ALKALI SOILS

The method of mixing the alkali salts and soil consisted of weighing out sufficient soil to equal the desired moisture-free amount required and transferring to a rotary concrete mixer. To this soil was added the required amount of the alkali salts. The mixing was continued until a complete and uniform

soil-alkali-mixture was obtained. Two 4-gallon jars were filled with a weighed quantity of soil. In addition a 2-gallon jar was filled from the same mix. Crops were grown on the 4-gallon jars, and the 2-gallon jar of soil served as a non-cropped check. All of the salt-soil concentrations were prepared in this manner.

After the entire series of pots was prepared, distilled water was added to each jar in amounts sufficient to bring the moisture content to approximately 20 per cent. After the soil had stood long enough to insure a uniform moisture condition, samples were taken from the duplicate jars for analysis in the following manner: two cores of soil were taken from each duplicate jar by means of a brass tube  $1\frac{1}{2}$  inches in diameter and sufficiently long to take a soil core through the entire depth of the jar. An analysis was made on a composite sample of the four cores. The results were taken as the average salt content of the duplicate jars. After the growth of each crop a composite sample of three cores was taken from each of the duplicate jars, and analyzed. All percentages are calculated on the basis of anhydrous soil.

The method of analyzing the soil for alkali salts in use in this laboratory has already been described in a former publication (4) and will not be repeated here.

#### EXPERIMENTAL WORK

Eighty-four 4-gallon jars were filled with equal amounts of soil to which various alkali concentrations and combinations were added. The series represents 40 different treatments in duplicate, and also 4 check jars of soil which received no alkali applications. The series of jars were placed in the greenhouse and enough distilled water added to increase the moisture content of the soil to 15 or 20 per cent. After standing a few days to insure a uniform soil moisture, the soils were sampled and alkali salts determined. The sample holes were then filled in and 15 kernels of Blue Stem wheat were planted in each duplicate jar. The soils were kept at an approximate moisture content of 18 per cent during the growing period. Data were taken at frequent intervals on germination, rate of growth, time of heading out, total yield of crops and the general appearance of the plants in all treatments. The number of plants in each jar was reduced to 8 when their height reached approximately 15 inches. At the time of maturity, the crop was harvested, dried and weighed. The grain was threshed and weighed separately. Samples of soil were taken from each jar and analyzed for the alkali salt content.

After the removal of the first crop and when the soil was sampled, it was turned out of each jar, thoroughly mixed and returned to the jar, moistened and another crop of wheat planted. This second crop was grown and records were taken in the same manner as for the first.

Table 2 contains data showing the concentrations of alkali salts added to the prepared soils; the initial recoverable alkali concentrations together with the recoverable alkali after removing the first and second crops. Table 3 shows the percentage of germination of the wheat, and the yield for each crop.

TABLE 2  
Average of salts recovered from duplicate pots

POT NUMBER	TREATMENTS			INITIAL SAMPLING				FIRST CROP				SECOND CROP			
	NaCO <sub>3</sub>	NaCl	NaSO <sub>4</sub>	NaCO <sub>3</sub>	NaCl	NaSO <sub>4</sub>	Total	NaCO <sub>3</sub>	NaCl	NaSO <sub>4</sub>	Total	NaCO <sub>3</sub>	NaCl	NaSO <sub>4</sub>	Total
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
141	Check			0.034	0.000	0.020	0.054	0.026	0.000	0.005	0.031	0.034	0.000	0.011	0.046
79	0.20			0.096	0.000	0.005	0.101	0.088	0.000	0.006	0.094	0.097	0.000	0.014	0.111
81	0.40			0.171	0.000	0.007	0.178	0.134	0.000	0.006	0.141	0.160	0.000	0.008	0.169
83	0.60			0.231	0.000	0.006	0.237	0.190	0.000	0.005	0.195	0.204	0.000	0.006	0.210
85	0.90			0.383	0.000	0.009	0.392	0.312	0.000	0.005	0.317	0.310	0.000	0.011	0.321
87		0.10		0.036	0.067	0.008	0.111	0.027	0.095	0.000	0.123	0.033	0.046	0.002	0.081
89		0.20		0.036	0.134	0.007	0.177	0.026	0.182	0.006	0.214	0.053	0.072	0.005	0.131
91		0.40		0.036	0.254	0.006	0.296	0.023	0.257	0.001	0.281	0.051	0.064	0.003	0.118
93			0.20	0.031	0.000	0.143	0.174	0.023	0.001	0.185	0.209	0.036	0.000	0.197	0.233
95			0.40	0.031	0.000	0.306	0.337	0.027	0.000	0.395	0.422	0.033	0.003	0.348	0.384
97			0.60	0.036	0.000	0.481	0.517	0.025	0.000	0.537	0.563	0.035	0.000	0.464	0.499
99			0.90	0.029	0.000	0.697	0.726	0.024	0.001	0.755	0.780	0.035	0.000	0.652	0.687
101	0.10	0.10		0.049	0.092	0.013	0.154	0.047	0.071	0.010	0.128	0.057	0.032	0.010	0.100
103	0.30	0.05		0.128	0.052	0.007	0.187	0.127	0.028	0.009	0.164	0.115	0.018	0.012	0.146
105	0.10	0.30		0.053	0.268	0.006	0.327	0.042	0.208	0.005	0.256	0.052	0.091	0.003	0.147
107	0.60	0.10		0.227	0.100	0.000	0.327	0.201	0.078	0.012	0.292	0.207	0.036	0.008	0.252
109	0.20	0.20		0.086	0.118	0.007	0.211	0.078	0.102	0.003	0.184	0.095	0.051	0.004	0.150
111		0.05		0.031	0.046	0.191	0.268	0.019	0.044	0.159	0.222	0.038	0.025	0.126	0.190
113		0.30		0.034	0.234	0.124	0.392	0.021	0.240	0.065	0.326	0.043	0.116	0.062	0.221
121		0.10		0.029	0.062	0.302	0.393	0.020	0.071	0.313	0.405	0.037	0.057	0.309	0.404
123		0.10		0.026	0.079	0.526	0.631	0.020	0.109	0.397	0.527	0.019	0.058	0.476	0.554
125	0.10			0.057	0.000	0.091	0.148	0.052	0.000	0.120	0.172	0.056	0.000	0.074	0.130
127	0.20			0.086	0.000	0.157	0.243	0.096	0.000	0.138	0.234	0.080	0.000	0.148	0.228
129	0.30			0.129	0.000	0.332	0.461	0.124	0.000	0.175	0.299	0.183	0.002	0.153	0.338
131	0.20			0.084	0.000	0.471	0.555	0.082	0.000	0.488	0.570	0.077	0.000	0.478	0.555

133	0.60		0.10	0.242	0.000	0.082	0.324	0.216	0.000	0.063	0.279	0.219	0.003	0.047	0.269
135	1.00		0.10	0.379	0.000	0.066	0.445	0.328	0.002	0.096	0.426	0.340	0.007	0.064	0.412
137	0.05	0.05	0.05	0.039	0.053	0.076	0.168	0.040	0.016	0.028	0.084	0.048	0.015	0.025	0.088
139	0.10	0.10	0.10	0.056	0.073	0.163	0.292	0.049	0.080	0.099	0.228	0.066	0.038	0.062	0.166
143	0.20	0.10	0.10	0.095	0.091	0.122	0.308	0.099	0.056	0.071	0.226	0.102	0.043	0.087	0.232
145	0.40	0.05	0.10	0.178	0.061	0.116	0.355	0.186	0.045	0.099	0.331	0.169	0.019	0.048	0.236
147	0.60	0.10	0.20	0.245	0.098	0.189	0.532	0.223	0.089	0.188	0.500	0.202	0.078	0.176	0.475
24	0.40	0.10	0.40	0.147	0.096	0.386	0.629	0.152	0.080	0.287	0.520	0.138	0.043	0.219	0.401
26	0.20	0.05	0.40	0.079	0.034	0.442	0.555	0.058	0.043	0.628	0.790	0.086	0.027	0.355	0.468
2	0.20	0.05	0.80	0.080	0.035	0.875	0.990	0.036	0.053	0.660	0.750	0.062	0.023	0.590	0.676
4	0.05	0.05	0.60	0.034	0.037	0.724	0.795	0.073	0.066	0.396	0.535	0.040	0.027	0.515	0.583
12	0.10	0.05	0.10	0.057	0.040	0.200	0.297	0.057	0.036	0.081	0.175	0.055	0.036	0.095	0.187
18	0.40	0.10	0.60	0.094	0.065	0.453	0.612	0.106	0.110	0.457	0.673	0.096	0.083	0.551	0.731
31	0.30	0.20	0.20	0.100	0.138	0.179	0.417	0.085	0.175	0.172	0.432	0.109	0.183	0.217	0.509
34	0.10	0.20	0.20	0.053	0.106	0.199	0.358	0.042	0.183	0.143	0.368	0.043	0.126	0.178	0.347
75	0.10	0.40	0.10	0.047	0.271	0.086	0.404	0.043	0.253	0.057	0.354	0.049	0.146	0.068	0.264
				0.037	0.000	0.003	0.040	0.036	0.000	0.004	0.041	0.036	0.000	0.006	0.041

Tables 4, 5, 6 and 7 are made up of averages for duplicate pots similarly compiled to show the particular combinations under discussion. Table 8

TABLE 3  
*Averages of percentage germination and of crop yields, regarding the check as 100 per cent*

POT NUMBER	TREATMENTS			GERMINATION		YIELD		
	Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	First crop	Second crop	First crop	Second crop	Total
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
141	Check			96	96	100.0	100.0	100.0
79	0.20			86	86	70.7	121.0	94.3
81	0.40			70	87	90.9	192.8	120.6
83	0.60			86	67	59.6	31.4	41.1
85	0.90			50	70	0.0	0.0	0.0
87		0.10		90	93	108.2	87.0	102.0
89		0.20		80	93	103.0	101.0	102.7
91		0.40		63	90	79.4	139.2	96.7
93			0.20	93	93	101.6	95.1	99.8
95			0.40	90	90	106.3	142.8	117.0
97			0.60	96	86	112.7	119.6	114.9
99			0.90	90	96	91.1	162.5	111.3
101	0.10	0.10		70	90	95.4	124.8	104.1
103	0.30	0.05		93	100	97.3	150.9	113.1
105	0.10	0.30		86	93	64.0	185.3	99.7
107	0.60	0.10		80	87	56.5	215.1	103.0
109	0.20	0.20		90	86	97.3	173.8	118.6
111		0.05	0.20	86	90	98.0	113.1	101.7
113		0.30	0.10	90	90	72.1	189.6	106.8
121		0.10	0.40	73	96	60.5	180.9	95.8
123		0.10	0.60	93	100	50.4	233.2	107.5
125	0.10		0.10	80	66	98.2	107.6	98.6
127	0.20		0.20	90	100	99.4	143.3	112.2
129	0.30		0.40	80	90	101.1	201.5	130.6
131	0.20		0.60	83	90	112.2	161.3	126.5
133	0.60		0.10	76	90	64.2	147.2	96.7
135	1.00		0.10	43	77	0.0	0.0	0.0
137	0.05	0.05	0.05	86	86	105.9	132.1	113.7
139	0.10	0.10	0.10	83	96	107.8	109.1	107.1
143	0.20	0.10	0.10	86	86	113.8	140.6	121.6
145	0.40	0.05	0.10	90	90	124.5	151.0	132.5
147	0.60	0.10	0.20	76	76	29.5	108.7	52.6
24	0.40	0.10	0.40	80	90	73.9	187.2	207.2
26	0.20	0.05	0.40	93	86	103.8	216.3	139.7
2	0.20	0.05	0.80	76	70	46.0	182.2	85.9
4	0.05	0.05	0.60	87	96	98.1	201.5	128.4
12	0.10	0.05	0.10	96	86	90.5	123.2	102.3
18	0.40	0.10	0.60	90	90	58.6	156.0	87.3
31	0.30	0.20	0.20	96	83	56.7	146.4	83.0
34	0.10	0.20	0.20	86	100	59.8	176.5	94.1
75	0.10	0.40	0.10	56	83	18.0	161.1	59.3

contains the data for the fallow pots showing salt additions and recoveries corresponding to those shown in table 2. The averages of duplicate pots have

TABLE 4  
*Salt combinations in which sodium carbonate predominates*

NUMBER	CONCENTRATION OF ALKALI ADDED			CONCENTRATION OF ALKALI RECOVERED				CROP YIELD— FIRST CROP
	Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Total	
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
83	0.6			0.190	0.000	0.050	0.195	59.6
107	0.6	0.1		0.201	0.078	0.012	0.291	56.5
133	0.6	0.1		0.216	0.000	0.063	0.279	64.2
147	0.6	0.1	0.1	0.223	0.089	0.188	0.500	29.5

TABLE 5  
*Combinations showing a medium concentration of sodium carbonate*

NUMBER	CONCENTRATION OF ALKALI ADDED			CONCENTRATION OF ALKALI RECOVERED				CROP YIELD— FIRST CROP
	Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Total	
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
81	0.4			0.134	0.000	0.006	0.141	90.0
103	0.3	0.05		0.127	0.028	0.009	0.164	97.3
129	0.3		0.4	0.124	0.000	0.175	0.299	101.1
143	0.2	0.10	0.1	0.099	0.056	0.071	0.226	113.8
24	0.4	0.10	0.4	0.152	0.080	0.287	0.520	73.9
18	0.4	0.10	0.6	0.106	0.110	0.457	0.673	58.6
31	0.3	0.20	0.4	0.085	0.175	0.172	0.432	56.7
109	0.2	0.20		0.078	0.102	0.003	0.184	97.3

TABLE 6  
*Salt combinations in which sodium chloride predominates*

NUMBER	CONCENTRATION OF ALKALI ADDED			CONCENTRATION OF ALKALI RECOVERED				CROP YIELD— FIRST CROP
	Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Total	
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
89		0.2		0.026	0.182	0.006	0.214	103.0
109	0.2	0.2		0.078	0.102	0.003	0.184	97.3
123		0.2	0.6	0.020	0.109	0.397	0.527	50.4
18	0.4	0.1	0.6	0.106	0.110	0.457	0.673	58.6
31	0.3	0.2	0.2	0.085	0.175	0.172	0.432	56.7
34	0.1	0.2	0.2	0.042	0.183	0.143	0.368	59.8
91		0.4		0.023	0.257	0.001	0.281	79.4
105	0.1	0.3		0.042	0.208	0.005	0.256	64.0
113		0.3	0.1	0.021	0.240	0.065	0.326	72.1
75	0.1	0.4	0.1	0.043	0.253	0.057	0.354	18.0

been plotted in the graphs in figures 1, 2 and 3, showing the amount of salt applied, the average amount recovered at each determination and the average

of crop results expressed in percentage above or below the check. The average of the check pots is considered 100 per cent. The first number of the set of duplicate pots is used to represent the average in the graphs.

In the discussion of the tables that follows, the term maximum tolerance is used to express the concentration of a single salt at which a decrease in crop growth consistently appears. There is found a relatively wide range between this point and that at which a marked decrease in crop-growth results. This amount of recoverable salt is called the critical concentration. The terms are arbitrarily assigned to these rather well defined points in the toxicity range and used for convenience in discussing the data.

TABLE 7  
*Salt combinations in which sodium sulfate predominates*

NUMBER	CONCENTRATION OF ALKALI ADDED			CONCENTRATION OF ALKALI RECOVERED				CROP YIELD— FIRST CROP
	Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Total	
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	
97			0.6	0.025	0.000	0.537	0.563	112.7
99			0.9	0.024	0.001	0.755	0.780	91.1
123		0.10	0.6	0.020	0.109	0.397	0.527	50.4
131	0.20		0.6	0.082	0.000	0.488	0.570	112.2
2	0.20	0.05	0.8	0.036	0.053	0.660	0.750	46.0
4	0.05	0.05	0.6	0.073	0.066	0.396	0.535	98.0
18	0.40	0.10	0.6	0.106	0.110	0.457	0.673	58.6
95			0.4	0.027	0.000	0.395	0.422	106.3
121		0.10	0.4	0.020	0.071	0.313	0.405	60.5
129	0.30		0.4	0.124	0.000	0.175	0.299	101.1
24	0.40	0.10	0.4	0.152	0.080	0.287	0.520	73.9
26	0.20	0.05	0.4	0.058	0.043	0.688	0.790	103.8

In comparing the graph numbers 83, 107, 133, 147, the striking feature is the increased recovery of sodium carbonate salts when chlorides and sulphates are present either alone or in combination. Slightly more sodium carbonate is recovered when sodium sulfate is present than when sodium chloride is added. In the face of this recovery, the yield of crop is slightly higher in the sodium sulfate addition, which in turn shows a higher carbonate recovery. This indicates a lower toxicity for sodium sulfate than sodium chloride. When the concentrations 0.1 per cent sodium chloride and 0.1 per cent sodium sulfate are added to 0.6 per cent sodium carbonate, the sodium carbonate recovery is greatest. Here the total salt concentration is sufficient to reduce the yield 75 per cent. It must be remembered that 0.19 to 0.22 per cent recoverable sodium carbonate is very near the critical concentration. Very little additional salt is necessary at this concentration entirely to inhibit growth.

The series reported in table 5, gave recoveries of sodium carbonate within a close range, but varying recoveries of sodium chloride and sodium sulfate. The crop growth appeared to be inversely proportional to the recoveries of

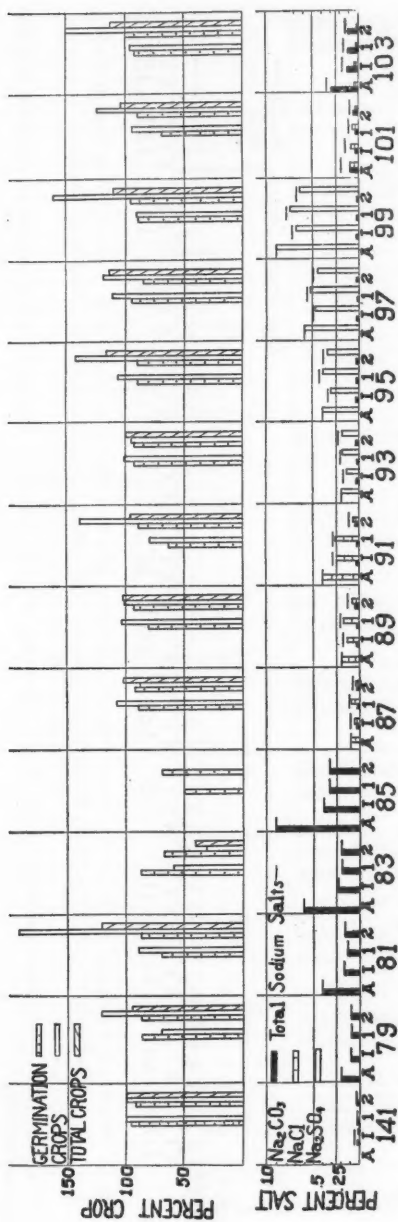


FIG. 1. GRAPHS OF AVERAGES OF DUPLICATE POTS, SHOWING ADDITIONS AND RECOVERIES OF EACH SALT AND OF TOTAL SODIUM SALTS, GERMINATION OF EACH CROP, PERCENTAGE YIELD OF EACH CROP, AND OF TOTAL OF THE TWO CROPS, USING THE AVERAGE OF THE CHECKS AS 100 PER CENT

A, salts added. I, salts recovered at initial sampling. 1, first crop and salts recovered when first crop is harvested. 2, second crop and final salt recovery.

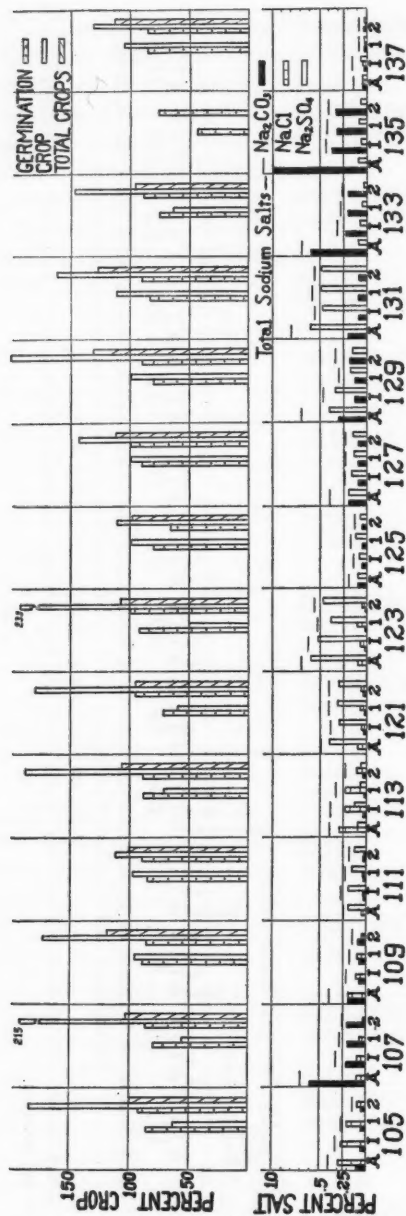


FIG. 2. GRAPHS OF AVERAGES OF DUPLICATE POTS, SHOWING ADDITIONS AND RECOVERIES OF EACH SALT AND OF TOTAL SODIUM SALTS, GERMINATION OF EACH CROP, PERCENTAGE YIELD OF EACH CROP, AND OF TOTAL OF THE TWO CROPS, USING THE AVERAGE OF THE CHECKS AS 100 PER CENT

A, salts added. I, salts recovered at initial sampling. 1, first crop and salts recovered when first crop was harvested. 2, second crop and final salt recovery.

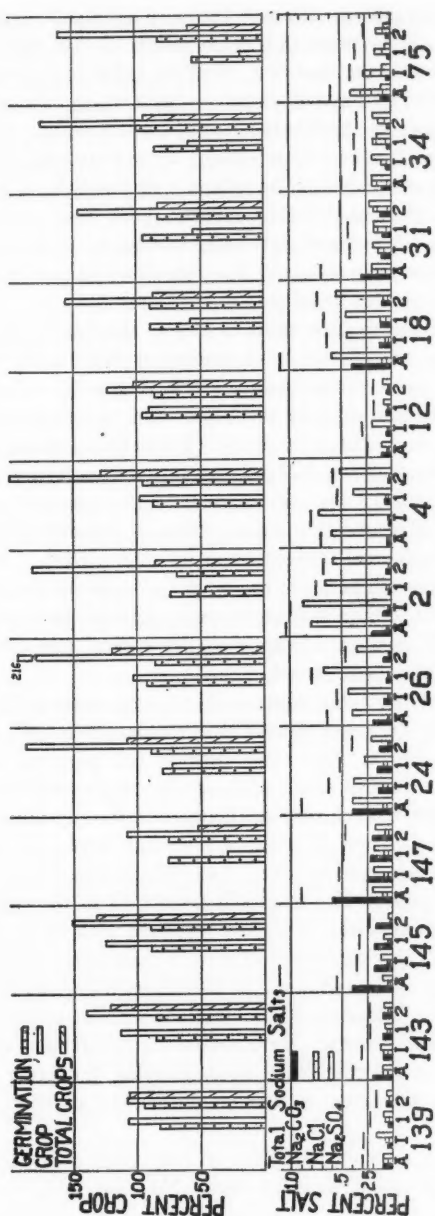


FIG. 3. GRAPHS OF AVERAGES OF DUPLICATE POTS, SHOWING ADDITIONS AND RECOVERIES OF EACH SALT AND OF TOTAL SODIUM SALTS, GERMINATION OF EACH CROP, PERCENTAGE YIELD OF EACH CROP, AND OF TOTAL OF THE TWO CROPS, USING THE AVERAGE OF THE CHECKS AS 100 PER CENT

A, salts added. 1, salts recovered at initial sampling. 2, first crop and salts recovered when first crop was harvested. 2, second crop and final salt recovery.

sodium chloride, while the sodium carbonate recovery remained approximately a constant. Variations in recovery of sodium sulfate do not seem to affect yield greatly in the above combinations. Sodium chloride recovery is the chief factor. The effect of sodium sulfate recoveries is chiefly shown when the concentration of carbonate or chloride is near the critical point. A recovery of 0.1 per cent sodium carbonate in water extract of the soil closely approaches the maximum tolerance concentration for wheat. Any additional percentage recovery is shown in a decreased yield. At the above observed maximum tolerance concentration of sodium carbonate, variations in either sodium chloride or sodium sulfate recoveries will show an effect on crop yield. The former salt shows much greater toxicity than the latter.

Table 6 contains data showing the effect of sodium chloride on crop growth when it is present in the soil solution in an amount approximating maximum tolerance and the critical concentration for wheat growth. Both groups represent individual sodium chloride recoveries and recoveries of sodium chloride in combination with other alkali salts. For sodium chloride the maximum tolerance is between 0.18 and 0.25 per cent expressed as recoverable salt. In general it approximates 0.2 per cent expressed as recoverable salt. Any increase in percentage of recoverable sodium chloride, however slight, tends to approach rapidly the critical concentration for crop growth. Any slight increase in the percentage recoveries of the other two salts when in combination with the 0.2 per cent sodium chloride recovery rapidly changes the effect on crop growth from maximum tolerance to the critical concentration or sometimes entirely inhibits plant growth.

In the second part of the table where 0.25 per cent recoverable sodium chloride is observed, very slight increases of recoverable salts rapidly approach total inhibition of crop growth. This concentration (0.25 per cent) of sodium chloride is very near the limit of alkali tolerance for crop growth and will be influenced by the recovery of even very small amounts of other salts.

In comparing graphs 147 and 24 with very similar recoveries of sodium chloride, the effect of an increased recovery of sodium carbonate is very clearly shown by the reduced yield. The total salt recoveries in the combination showing the greater reduced yield, is slightly less than with the higher crop-yielding combination. This clearly shows the more toxic effect of sodium carbonate as compared with sodium sulfate. It also shows the added toxic effect of sodium chloride salts. These same combinations without sodium chloride were far less toxic to plant growth. Here is seen the added toxic effect of a small amount of sodium chloride when accompanying the other two salt concentrations, which in themselves do not show a marked toxic effect on wheat growth.

Table 7 contains data showing the effect on crop yield of sodium sulfate alone and in combination with other alkali salts. No appreciable effect on the growth of wheat of even the highest recoveries of sodium sulfate is noted. All concentrations of sodium sulfate used in this experiment were below the toxic limit for this salt.

High concentrations of sodium sulfate when accompanied by small recoveries of sodium chloride show a marked decrease in crop yield, due to the toxic effect of the sodium chloride. This is shown clearly in the graphic illustration of results of treatments numbers 97, 123 and 121. The addition of 0.6 per cent sodium sulfate shows a normal yield, while this amount accompanied by 0.1 per cent sodium chloride shows a decrease in yield approximating 50 per cent. A 40 per cent decrease in yield is shown by 0.4 per cent of sodium sulfate in combination with 0.1 per cent sodium chloride. The reduction in yield is chiefly due to the sodium chloride rather than the sodium sulfate addition. This amount of sodium chloride when present alone in a soil shows no material effect on crop growth. This illustrates clearly an additive effect of these two salt concentrations each of which when present alone, shows a normal crop growth.

High concentrations of sodium sulfate accompanied by varying concentrations of sodium carbonate do not appear to influence crop growth until the concentration of sodium carbonate becomes greater than the maximum tolerance concentration for this salt. This is shown in graphs numbers 97, 129, 131.

In all salt combinations in which sodium sulfate predominates there is observed an additional toxicity due to sodium chloride, wherever it is present in the combination. This increased toxicity of sodium chloride is reduced by the presence of sodium carbonate concentrations that in themselves approach the maximum tolerance for this salt.

The above data present the first indication of a possible antagonism of ions when present in combinations in the soil solution. Much data are at hand on other crops that present clearer examples of possible antagonism of ions, hence a complete discussion of the effect of a combination of salts will be reserved until data on all crops are presented.

#### DISCUSSION OF THE EFFECT OF ALKALI SALTS ON A SECOND CROP OF WHEAT

All concentrations of sodium carbonate except the two highest, showed a marked stimulating effect on plant growth on the second crop. The highest concentration of added salt, namely, 0.9 per cent with a recovery of 0.31 per cent resulted in a total inhibition of growth.

With sodium chloride the smaller additions which showed stimulation in the first crop, show a slight decrease in yield in the second. In the higher additions where a decrease in crop growth was observed in the first crop, a stimulation occurs in the second. Generally speaking, the yield of the second crop varies inversely with the first crop, that is, if the first crop is low, the second is high, and vice versa.

The same observation holds with the sodium sulfate treatments as with sodium chloride. The higher treatments show a slight depression in the first crop and a large stimulation in the second. The greatest concentrations give the highest yield of wheat in the second crop.

TABLE 8  
*Salt recovery on fallow plots*

POT NUMBER	TREATMENT			INITIAL SAMPLING				FIRST CROP				SECOND CROP			
	Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Total equivalent Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Total sodium salts	Total equivalent Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Total sodium salts	Total equiva- lent Na <sub>2</sub> CO <sub>3</sub>	NaCl	Na <sub>2</sub> SO <sub>4</sub>	Total sodium salts
141A	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
79A	Check			0.036	0.000	0.011	0.047	0.025	0.000	0.008	0.032	0.022	0.000	0.008	0.030
81A	0.20			0.096	0.000	0.005	0.101	0.087	0.000	0.010	0.097	0.065	0.000	0.009	0.074
83A	0.40			0.171	0.000	0.007	0.178	0.157	0.000	0.007	0.164	0.135	0.000	0.015	0.150
85A	0.60			0.231	0.000	0.006	0.237	0.231	0.000	0.007	0.238	0.204	0.000	0.022	0.226
87A	0.90			0.383	0.000	0.009	0.392	0.345	0.000	0.008	0.353	0.311	0.000	0.015	0.326
89A		0.10		0.036	0.067	0.008	0.111	0.028	0.100	0.006	0.134	0.020	0.127	0.012	0.159
91A		0.20		0.036	0.134	0.007	0.177	0.023	0.170	0.007	0.200	0.019	0.190	0.010	0.219
93A		0.40		0.036	0.254	0.006	0.296	0.025	0.364	0.005	0.394	0.025	0.373	0.009	0.407
95A			0.20	0.031	0.000	0.143	0.174	0.025	0.000	0.177	0.202	0.025	0.000	0.157	0.182
97A			0.40	0.031	0.000	0.306	0.337	0.028	0.000	0.446	0.474	0.020	0.000	0.364	0.384
99A			0.60	0.036	0.000	0.481	0.517	0.028	0.000	0.600	0.628	0.019	0.000	0.510	0.529
101A			0.90	0.029	0.000	0.697	0.726	0.020	0.004	0.835	0.859	0.020	0.000	0.850	0.870
103A	0.10	0.10		0.049	0.092	0.013	0.154	0.043	0.095	0.016	0.154	0.033	0.105	0.019	0.157
105A	0.30	0.05		0.128	0.052	0.007	0.187	0.110	0.047	0.006	0.163	0.098	0.058	0.012	0.168
107A	0.10	0.30		0.053	0.268	0.006	0.327	0.037	0.275	0.006	0.318	0.033	0.249	0.013	0.295
109A	0.60	0.10		0.227	0.100	0.000	0.327	0.188	0.082	0.017	0.287	0.188	0.096	0.027	0.311
111A	0.20	0.10		0.086	0.118	0.007	0.211	0.047	0.201	0.010	0.258	0.094	0.165	0.012	0.271
113A		0.05	0.20	0.031	0.046	0.191	0.268	0.027	0.040	0.045	0.112	0.022	0.045	0.195	0.262
121A		0.30	0.10	0.034	0.234	0.124	0.392	0.027	0.270	0.111	0.406	0.022	0.266	0.112	0.400
123A		0.10	0.40	0.029	0.062	0.302	0.393	0.020	0.102	0.370	0.492	0.017	0.100	0.382	0.499
125A		0.10	0.60	0.026	0.079	0.526	0.631	0.020	0.083	0.532	0.635	0.017	0.093	0.451	0.561
127A	0.10		0.10	0.057	0.000	0.091	0.148	0.043	0.000	0.092	0.135	0.034	0.000	0.083	0.117
127A	0.20		0.20	0.086	0.000	0.157	0.243	0.064	0.000	0.189	0.253	0.052	0.000	0.172	0.224

129A	0.30		0.40	0.129	0.000	0.332	0.461	0.103	0.000	0.307	0.410	0.094	0.000	0.388	0.482
131A	0.20		0.60	0.084	0.000	0.471	0.555	0.039	0.000	0.608	0.647	0.040	0.000	0.610	0.650
133A	0.60		0.10	0.242	0.000	0.082	0.324	0.150	0.000	0.100	0.250	0.209	0.000	0.088	0.297
135A	1.00		0.10	0.379	0.000	0.066	0.445	0.319	0.005	0.083	0.407	0.294	0.003	0.125	0.422
137A	0.05	0.05	0.05	0.039	0.053	0.076	0.168	0.029	0.031	0.051	0.115	0.022	0.063	0.045	0.130
139A	0.10	0.10	0.10	0.056	0.073	0.163	0.292	0.025	0.110	0.108	0.243	0.030	0.095	0.091	0.219
143A	0.20	0.10	0.095	0.095	0.091	0.122	0.308	0.063	0.058	0.086	0.207	0.052	0.088	0.142	0.282
145A	0.40	0.05	0.10	0.178	0.061	0.116	0.355	0.134	0.042	0.067	0.243	0.135	0.063	0.115	0.313
147A	0.60	0.05	0.10	0.245	0.098	0.189	0.532	0.194	0.077	0.151	0.422	0.172	0.098	0.178	0.548
24A	0.40	0.10	0.40	0.147	0.096	0.386	0.629	0.109	0.084	0.341	0.634	0.103	0.093	0.324	0.520
26A	0.20	0.05	0.40	0.079	0.034	0.442	0.555	0.052	0.032	0.356	0.440	0.052	0.063	0.439	0.554
2A	0.20	0.05	0.80	0.080	0.035	0.875	0.990	0.040	0.091	0.701	0.832	0.037	0.055	0.698	0.790
4A	0.05	0.05	0.60	0.034	0.037	0.724	0.795	0.018	0.022	0.516	0.556	0.025	0.036	0.464	0.523
12A	0.10	0.05	0.10	0.057	0.040	0.200	0.297	0.035	0.017	0.057	0.109	0.047	0.011	0.025	0.083
18A	0.40	0.10	0.60	0.121	0.065	0.453	0.639	0.068	0.044	0.401	0.513	0.098	0.045	0.208	0.351
31A	0.30	0.20	0.20	0.100	0.138	0.179	0.417	0.072	0.058	0.137	0.267	0.074	0.068	0.065	0.207
34A	0.10	0.20	0.053	0.053	0.106	0.199	0.358	0.025	0.072	0.175	0.272	0.034	0.088	0.073	0.195
75A	0.10	0.40	0.10	0.047	0.271	0.086	0.404	0.029	0.166	0.067	0.262	0.034	0.149	0.036	0.219

When the various combinations of salt additions are compared it is seen that whenever there has been a depression in the first crop yield, there is usually an increase in the second crop. The amount of increase is somewhat proportional to the amount of decrease in the yield in the first crop. The only combination which completely inhibited crop growth in both plantings is 1 per cent sodium carbonate and 0.1 per cent sodium sulfate, the 1 per cent sodium carbonate alone being sufficient to inhibit completely the growth of wheat.

The cause of the marked stimulating effect noted in the second crop yields, in all but the highest concentrations of alkali salts, will be discussed in detail when all the tolerance data are presented on other crops. This particular problem has been under investigation by the writers for some time. The possible reasons for this stimulation are many, namely, a rearrangement of soil bases, which in turn may result in the liberation of more available plant-foods; the favorable effect that certain alkali salts have on improving the physical conditions of soil; the effect on the bacterial flora of soils. All these studies have been under way and will be reported from this station at a later date. That all factors play a part in causing this stimulation is indicated by the results secured thus far. A recent publication by Greaves, Hirst and Lund (1) reporting leaching experiments corroborates the possibility of the liberation of plant-foods.

#### DISCUSSION OF THE TOTAL YIELD OF THE TWO CROPS

No discussion will be given on the effect of alkali salts on the total of the two crop yields for the reason that these crop yields compensate one another; the first crop showing a depression and the second, a stimulation. In order to secure more comparable total yields, all later tolerance studies have been carried out to include three or four crops. The total yields or their average, therefore, more truly represent the actual effect of added alkali salts on the yield of crops.

#### ALKALI RECOVERIES FROM FALLOWED AND CROPPED SOILS

As described in the plan of experiment a series of pots was prepared from each artificially prepared alkali soil and set aside to determine the effect of non-cropping as compared with cropping on the salt recovery. These pots were cared for in exactly the same manner as the duplicate pots on which crops were grown. They were sampled at the same periods as the wheat series.

An examination of the data shows considerable variation in the recoveries from the cropped and fallow pots. The general trend of the results, however, indicates that there is a persistent difference in the recovery of salts from the cropped and uncropped series.

The original alkali recoveries vary slightly for each of the triplicate pots. This is due to the difficulties, well known to those experienced in alkali soil studies, encountered in securing a uniform and equal distribution of alkali

salts throughout the soil as well as in sampling. For this reason conclusions should be based on the general average of results rather than on individual pots.

It is well known that a much smaller percentage of the added sodium carbonate can be recovered from a water extract of soil than with sodium chloride or sodium sulfate. The carbonate recoveries for the uncropped and cropped soils are both low, but the general trend of the results shows a lower recovery of the carbonate salts in the uncropped soils. This fact tends to show that under fallow conditions more carbonates are fixed or absorbed in the soil, and substantiates the conclusions drawn in a former publication (4) that carbonates undergo a change when added to a soil, being fixed as silicates or changed in form through a rearrangement of soil bases. With the cropped soils, more carbonate salts are recovered, due to the increased production of carbon dioxide which tends to prevent the fixing of the soluble carbonates into insoluble compounds.

The sodium chloride recoveries show more recoverable chloride in the fallow pots than in the cultivated crops. This may be partly due to the removal of a portion of the soluble chlorides by the crop growth.

There is considerable variation in the recoveries of the sulfate salts from the two series, showing, however, a slight tendency toward a lower recovery from the cropped soils which indicates some utilization of sulfates in crop growth.

#### THE EFFECT OF SALT CONCENTRATIONS ON RATE OF GERMINATION AND GROWTH

Data were secured on rate of germination, growth, and time of heading out for both crops. The data are so voluminous that only a general summary of the effect of the single salts and the combinations are given (table 3). The low concentrations of all single-salt additions showed very little effect on germination, rate of growth and time of heading out. The effect of high concentrations of the single salts is quite characteristic for each. Sodium chloride retards the germination at medium concentrations and at the highest concentrations used, the percentage of germination is materially lowered. When plants appear through the surface of the soil, the young plants grow very slowly and some die. If, however, they reach the height of 3 inches they usually continue to grow to maturity. The plants, however, grow rather spindling but are usually healthy looking and have a good color. The presence of sodium chloride in the soil hastens the heading out or fruiting period of the wheat.

For all concentrations except the extremely high ones sodium carbonate shows little retarding effect on germination. The highest concentrations do appreciably decrease the percentage of germination. The next two lower additions did not show an effect of inhibiting the germination, since the young plants quickly made their appearance. The effect of these concentrations was to kill the young plants as soon as they reached a height of approximately 3 to 5 inches. The appearance of the wheat plant when grown in low concentra-

tions of sodium carbonate is characteristic. The plant produces broad thick leaves and has an appearance slightly different from a wheat plant grown on a normal soil not containing alkali. In the higher concentrations, where plant growth is retarded, the wheat plants have an abnormal appearance, recognized by broad leaves, thick leaf sheaths and a stem which has a corroded appearance at the base. Sodium carbonate additions delay the heading out of the wheat.

Sodium sulfate additions were not large enough to kill the wheat plants. When other salts are present, with the high sulfate concentrations there is an effect similar to that shown by the sodium chloride treatments. These treatments speed up the heading out period and produce a spindling type of plant. Sodium sulfate showed practically no effect on rate or percentage of germination.

#### THE EFFECT OF ALKALI SALTS ON YIELD OF GRAIN

The effect of alkali salts on the yield of grain will not be discussed for the first crop, because it was grown during the winter months in the greenhouse. A lack of sunshine during this time delayed ripening. In addition, a mildew gained access to some of the plants during the latter period of growth, reducing grain yields. The second crop, however, was grown under more favorable conditions and very satisfactory grain yields resulted. In general the increase in grain yields parallels the increase of the total crop yields.

#### SUMMARY

##### *First crop*

Basing the observations on the recoverable rather than the added salts, the effects of alkali on the first crop of wheat are as follows:

Wheat was not affected by sodium carbonate until 0.1 per cent recoverable salt was found. At 0.2 per cent concentration there was evident toxicity; 0.3 per cent recoverable salt always resulted in a total crop failure.

Sodium chloride when present alone in the soil was not harmful to the growth of wheat until 0.2 per cent recoverable salt concentration was reached; 0.25 per cent recoverable sodium chloride showed a decided toxicity.

Recoveries of 0.75 per cent sodium sulfate failed to show any detrimental effect on crop yield. The tolerance for this concentration of sodium sulfate is materially decreased by the presence of 0.07 per cent of sodium chloride. In the presence of the same amount of sodium sulfate, sodium carbonate shows no effect until its own maximum tolerance limit of approximately 0.1 per cent is reached.

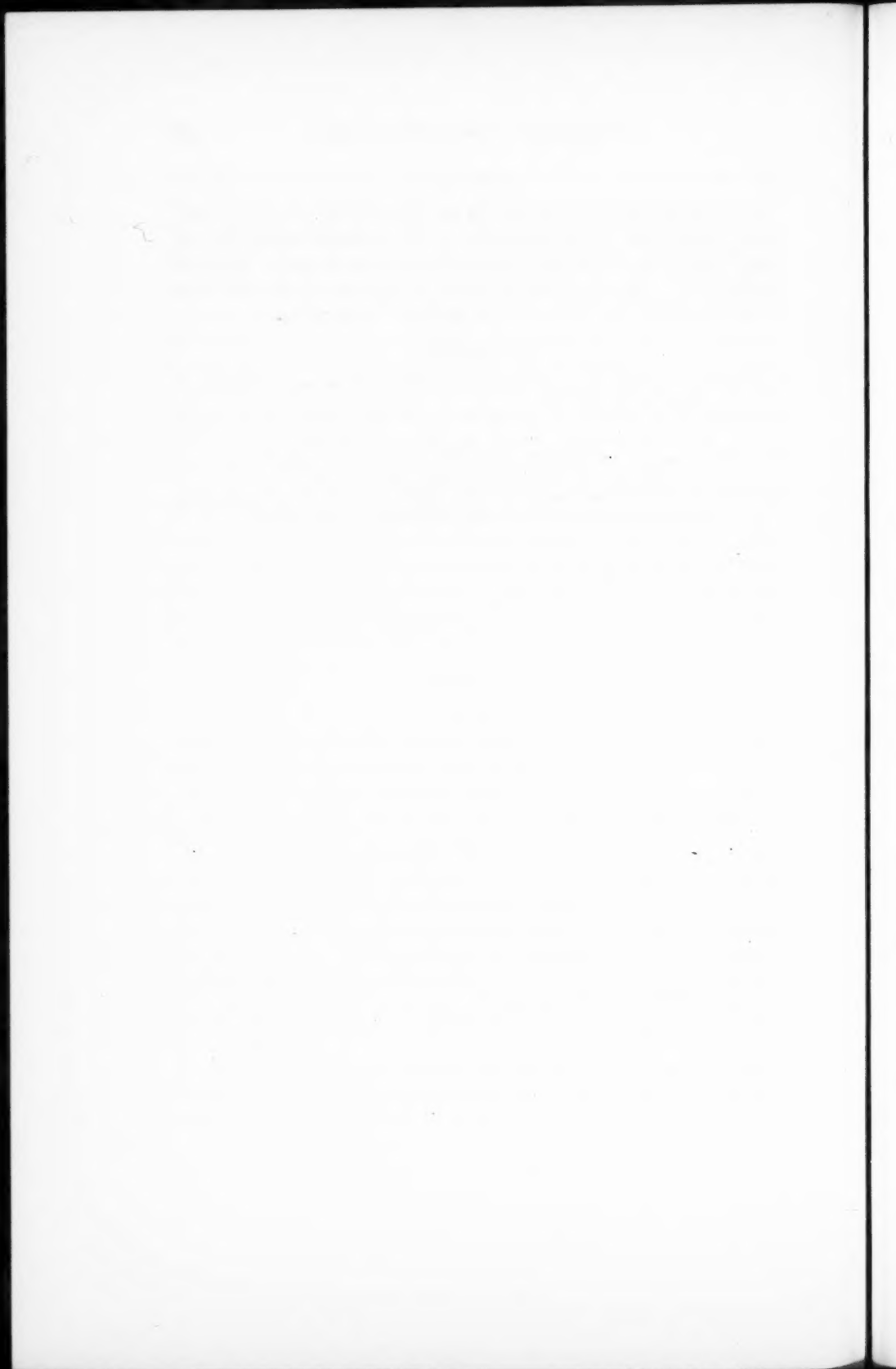
In combinations of sodium carbonate and sodium chloride, small recoveries of either salt had an influence on crop yield only when the other salt concentration approached its maximum tolerance.

*Second crop*

In the second crop, any toxic effect of the salts on plant growth is so effectively overshadowed by the stimulation of all treatments except the very highest carbonates, that no measurement of toxicity can be made. However, on other studies where more crops are grown on the same soil, this stimulation is overcome, and characteristic toxicities again become apparent.

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# EFFECT OF IRON AND ALUMINUM SALTS ON THE PHOSPHORUS RECOVERY FROM SOILS AND QUARTZ SAND TREATED WITH TENNESSEE ROCK OR DOUBLE ACID PHOSPHATE

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## INTRODUCTION

It has been shown in a previous paper (2) that different soils treated with either rock or acid phosphate allow certain phosphorus recovery by means of 0.2 *N.*  $\text{HNO}_3$ ; that this recovery from any particular soil is practically the same, regardless of whether phosphorus is applied in the form of double acid phosphate, or finely ground rock phosphate; and that the recovery of phosphorus from different soils, so treated, varies very greatly.

It was suggested in the paper referred to that this difference in phosphorus recovery from different soils may be due to the presence of iron and aluminum compounds with some additional influence from soluble silica and silicious compounds.

The present paper deals with the effect of adding ferric and aluminum chlorides in modifying the phosphorus recovery from some soils and sand, treated with phosphatic fertilizers.

## EXPERIMENTAL

The general method followed in this study is the same as reported previously (2), namely; to 25 gm. of soil or sand was added a certain amount of  $\text{FeCl}_3$  or  $\text{AlCl}_3$  (in solid form); then a certain amount of either rock or double acid phosphate was added; the whole mass was thoroughly mixed, moistened with distilled water to about 60 per cent of saturation; then it was allowed to stand for 7 days at room temperature, after which it was taken up with 250 cc. 0.2 *N.*  $\text{HNO}_3$ , shaken up for 3 hours, filtered and an aliquot taken for determination of phosphorus. In the phosphorus determination, the volumetric method was followed.

Three agricultural soils were used,—brown silt loam, brown gray silt loam, and black clay loam. These soils were of Champaign County, Illinois. Quartz sand, of a rather coarse texture, was used for comparison.

The ferric and aluminum chlorides were used in amounts equivalent to 0.1 and 0.2 gm. of salt per 25 gm. of soil or sand. The amount of phosphorus applied is indicated in the tables, and usually equalled 4 or 8 mgm.

of phosphorus. In one case, the same amount, 0.025 gm. of both phosphatic fertilizers was taken. Samples of soil or sand, treated with ferric or aluminum chloride, were left untreated with phosphates. This was done to see the effect of these salts on the phosphorus recovery from natural soil. In every case, the average of two determinations is hereby reported.

The results are summarized in tables 1, 2, 3, and 4, which are self-explanatory. The results as reported show the net amounts of phosphorus extracted from soils or sand, due to the added phosphorus. A blank to allow for the soil phosphorus was in each case previously subtracted and the relative efficiency of the phosphorus recovery was based on these net amounts.

TABLE 1  
*Extraction of phosphorus from 25 gm. of brown silt loam treated with either rock or acid phosphate containing 8 mgms. phosphorus*

MATERIAL EXTRACTED WITH 0.2 N NITRIC ACID	PHOSPHORUS RECOVERY	
	Phosphorus obtained	Relative efficiency
	mgm.	per cent
Soil alone.....	0.24	
Soil +0.1 gm. $\text{FeCl}_3$ .....	0.23	
Soil +0.2 gm. $\text{FeCl}_3$ .....	0.19	
Soil +0.1 gm. $\text{AlCl}_3$ .....	0.26	
Soil +0.2 gm. $\text{AlCl}_3$ .....	0.27	
Soil +0.050 gm. rock phosphate.....	4.66	100
Soil + rock phosphate +0.1 gm. $\text{FeCl}_3$ .....	4.16	89
Soil + rock phosphate +0.2 gm. $\text{FeCl}_3$ .....	3.88	84
Soil + rock phosphate +0.1 gm. $\text{AlCl}_3$ .....	4.78	102
Soil + rock phosphate +0.2 gm. $\text{AlCl}_3$ .....	4.77	102
Soil + 0.0344 gm. acid phosphate.....	4.41	100
Soil + acid phosphate +0.1 gm. $\text{FeCl}_3$ .....	4.11	93
Soil + acid phosphate +0.2 gm. $\text{FeCl}_3$ .....	4.08	93
Soil + acid phosphate +0.1 gm. $\text{AlCl}_3$ .....	4.67	106
Soil + acid phosphate +0.2 gm. $\text{AlCl}_3$ .....	4.78	108

The results obtained in this work, presented in tables 1, 2, 3, and 4, are rather interesting in as much as they show a considerable difference in effect produced by these two salts.

Ferric chloride added in these small amounts decreased the phosphorus recovery in every one of the three soils, the maximum decrease amounting to 16 per cent. Aluminum chloride, on the other hand, caused some stimulation of the phosphorus recovery in two of the three soils used. In the case of black clay loam, the increase was very pronounced, amounting, with 0.2 gm.

application, to 16 and 17 per cent with rock phosphate and double acid phosphate, respectively. In brown silt loam the stimulation was much less, and no stimulation was observed in brown gray silt loam. Neither ferric nor aluminum chloride had any influence on the phosphorus recovery in quartz sand

The results are noteworthy in connection with the fact that in agricultural literature dealing with the role of iron and aluminum in soil fertility, these two bases are often placed in one group as having many characteristics in common and influencing the soil solution in the same general direction. The

TABLE 2

*Extraction of phosphorus from 25 gm. of brown gray silt loam treated with approximately 4 mgm. of phosphorus in the form of either rock or acid phosphate*

MATERIAL EXTRACTED WITH 0.2 N NITRIC ACID	PHOSPHORUS RECOVERY	
	Phosphorus obtained	Relative efficiency
	mgm.	per cent
Soil alone.....	0.47	
Soil +0.1 gm. $\text{FeCl}_3$ .....	0.41	
Soil +0.2 gm. $\text{FeCl}_3$ .....	0.40	
Soil +0.1 gm. $\text{AlCl}_3$ .....	0.49	
Soil +0.2 gm. $\text{AlCl}_3$ .....	0.52	
Soil rock phosphate.....	3.42	100
Soil + rock phosphate +0.1 gm. $\text{FeCl}_3$ .....	3.29	96
Soil + rock phosphate +0.2 gm. $\text{FeCl}_3$ .....	3.07	90
Soil + rock phosphate +0.1 gm. $\text{AlCl}_3$ .....	3.44	101
Soil + rock phosphate +0.2 gm. $\text{AlCl}_3$ .....	3.46	101
Soil + acid phosphate.....	3.55	100
Soil + acid phosphate +0.1 gm. $\text{FeCl}_3$ .....	3.35	94
Soil + acid phosphate +0.2 gm. $\text{FeCl}_3$ .....	3.23	91
Soil + acid phosphate +0.1 gm. $\text{AlCl}_3$ .....	3.51	99
Soil + acid phosphate +0.2 gm. $\text{AlCl}_3$ .....	3.46	97

data from these experiments show that this is not always the case. In fact in their influence on the behavior of phosphorus in soils they are entirely different from one another. While iron inhibits the phosphorus going into solution, aluminum sometimes hastens it.

It should be noticed in this connection that the inhibitive action of ferric chloride does not have much of a residual effect. Indeed, what is held out of solution in the first of a series of extractions may be recovered with subsequent extractions. This was determined in an experiment with brown silt loam and brown gray silt loam in which five consecutive extractions of

phosphorus were made. After the first extraction was filtered and washed four times with distilled water the residue was treated with 250 cc. of fresh 0.2 N  $\text{HNO}_3$ , shaken up for 3 hours, filtered again and washed. This was repeated five times, and the results are summarized in tables 5 and 6.

The data are instructive. They show that ferric chloride causes a decrease in phosphorus recovery in the first extraction, but in the second extraction the residue yields a larger amount of phosphorus than from the untreated soil. Thus, at the end of the fifth extraction, there is nearly as much (or even more) phosphorus obtained as was present in the untreated

TABLE 3  
*Extraction of phosphorus from 25 gm. black clay loam treated with 0.025 gm. of either rock or acid phosphate*

MATERIAL EXTRACTED WITH 0.2 N NITRIC ACID	PHOSPHORUS RECOVERY	
	Phosphorus obtained	Relative efficiency
	mgm.	per cent
Soil alone .....	0.96	
Soil +0.1 gm. $\text{FeCl}_3$ .....	0.69	
Soil +0.2 gm. $\text{FeCl}_3$ .....	0.66	
Soil +0.1 gm. $\text{AlCl}_3$ .....	0.83	
Soil +0.2 gm. $\text{AlCl}_3$ .....	0.90	
Soil + rock phosphate .....	2.01	100
Soil + rock phosphate +0.1 gm. $\text{FeCl}_3$ .....	1.87	93
Soil + rock phosphate +0.2 gm. $\text{FeCl}_3$ .....	1.72	86
Soil + rock phosphate +0.1 gm. $\text{AlCl}_3$ .....	2.11	105
Soil + rock phosphate +0.2 gm. $\text{AlCl}_3$ .....	2.24	117
Soil + acid phosphate .....	2.44	100
Soil + acid phosphate +0.1 gm. $\text{FeCl}_3$ .....	2.27	93
Soil + acid phosphate +0.2 gm. $\text{FeCl}_3$ .....	1.98	81
Soil + acid phosphate +0.1 gm. $\text{AlCl}_3$ .....	2.68	110
Soil + acid phosphate +0.2 gm. $\text{AlCl}_3$ .....	2.84	116

soil. Taking all five extractions together, one notices that the amount of recovered phosphorus runs pretty much alike in all cases.

It was observed, as one notices in table 4, that neither ferric nor aluminum chlorides had any influence on the phosphorus recovery in quartz sand. The sand behaved very unlike the agricultural soils in this respect.

However, being void of any soluble salts in appreciable amounts, sand affords a very convenient medium for study. This particular sand was rather coarse in texture to resemble agricultural soil. For this reason, 25 gm. portions of silica flour, passing through a 200-mesh sieve, were treated with

0.5 gm.  $\text{FeCl}_3$ ,  $\text{AlCl}_3$  and  $\text{CaCO}_3$ , singly and in various combinations About 4 mgms. of phosphorus in the form of rock phosphate was added to this silica flour and wetted. The phosphorus extraction and determination were made as usual.

A 10-cc. aliquot of extracted solution, immediately after filtering, was taken and titrated against a standard alkali. This was done, in order to ascertain to what extent the reduction in acidity of the extractor influences the amount of phosphorus extracted from silica flour treated with different salts.

TABLE 4

*Extraction of phosphorus from 25 gm. of quartz sand treated with approximately 4 mgm. phosphorus in the form of either rock or acid phosphate*

MATERIAL EXTRACTED WITH 0.2 N NITRIC ACID	PHOSPHORUS RECOVERY	
	Phosphorus obtained	Relative efficiency
	mgm.	per cent
Sand alone.....	0.04	
Sand +0.1 gm. $\text{FeCl}_3$ .....	0.01	
Sand +0.2 gm. $\text{FeCl}_3$ .....	0.02	
Sand +0.1 gm. $\text{AlCl}_3$ .....	0.06	
Sand +0.2 gm. $\text{AlCl}_3$ .....	0.07	
Sand + rock phosphate.....	3.73	100
Sand + rock phosphate +0.1 gm. $\text{FeCl}_3$ .....	3.77	101
Sand + rock phosphate +0.2 gm. $\text{FeCl}_3$ .....	3.67	98
Sand + rock phosphate +0.1 gm. $\text{AlCl}_3$ .....	3.64	98
Sand + rock phosphate +0.2 gm. $\text{AlCl}_3$ .....	3.78	101
Sand + acid phosphate.....	3.67	100
Sand + acid phosphate +0.1 gm. $\text{FeCl}_3$ .....	3.68	100
Sand + acid phosphate +0.2 gm. $\text{FeCl}_3$ .....	3.80	103
Sand + acid phosphate +0.1 gm. $\text{AlCl}_3$ .....		
Sand + acid phosphate +0.2 gm. $\text{AlCl}_3$ .....	3.77	103

The results showing the percentage of phosphorus recovery, and the percentage of the original acidity in the resultant solution, are presented in figure 1. The results with this extremely fine quartz sand, or flour, correspond to those obtained with coarser quartz sand in that neither ferric chloride nor aluminum chloride, added alone, show any appreciable influence on the phosphorus recovery as compared with sand that had not been treated with these salts. The mixture of calcium carbonate and aluminum chloride was also without any influence, the recovery being 98.2 per cent of the check. Other mixtures, however, showed some inhibitive effect.

Thus, a mixture of calcium carbonate and ferric chloride reduced the recovery to about 89 per cent of the check, and the mixture of ferric chloride and aluminum chloride reduced the phosphorus recovery to 93.6 per cent. The mixture of calcium carbonate, ferric chloride and aluminum chloride cause a reduction to 92.3 per cent of the check.

TABLE 5

*Residual effect of 0.2 gm. of iron or aluminum chloride on the extraction of phosphorus from 25 gm. brown silt loam, treated with approximately 4 mgm. phosphorus in the form of either rock or acid phosphate*

Extraction with 0.2 N nitric acid was repeated 5 times

	PHOSPHORUS RECOVERY						RELATIVE VALUE OF FIRST EXTRACTION	RELATIVE VALUE OF TOTAL EXTRACTION
	1st extrac- tion	2nd extrac- tion	3rd extrac- tion	4th extrac- tion	5th extrac- tion	Total		
	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.		
Rock phosphate.....	1.86	0.47	0.24	0.13	0.09	2.79	100	100
Rock phosphate and FeCl <sub>3</sub> .....	1.52	0.57	0.26	0.12	0.06	2.53	82	91
Rock phosphate and AlCl <sub>3</sub> .....	1.95	0.38	0.18	0.09	0.03	0.63	105	94
Acid phosphate.....	1.75	0.46	0.21	0.12	0.02	2.56	100	100
Acid phosphate and FeCl <sub>3</sub> .....	1.52	0.57	0.27	0.15	0.06	2.57	87	100
Acid phosphate and AlCl <sub>3</sub> .....	1.86	0.38	0.21	0.09	0.00	2.54	106	99

TABLE 6

*Residual effect of 0.2 gm. of iron or aluminum chloride on the extraction of phosphorus from 25 gm. brown gray silt loam treated with approximately 4 mgm. phosphorus in the form of either rock or acid phosphate*

Extraction with 0.2 N nitric acid was repeated five times

	PHOSPHORUS RECOVERY						RELATIVE VALUE OF FIRST EXTRACTION	RELATIVE VALUE OF TOTAL EXTRACTION
	1st extrac- tion	2nd extrac- tion	3rd extrac- tion	4th extrac- tion	5th extrac- tion	Total		
	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.		
Rock phosphate.....	3.02	0.25	0.09	0.02	0.00	3.38	100	100
Rock phosphate and FeCl <sub>3</sub> .....	2.55	0.72	0.16	0.06	0.03	3.52	84	104
Rock phosphate and AlCl <sub>3</sub> .....	3.02	0.42	0.11	0.05	0.01	3.61	100	107
Acid phosphate.....	3.10	0.24	0.10	0.05	0.01	3.50	100	100
Acid phosphate and FeCl <sub>3</sub> .....	2.84	0.56	0.16	0.05	0.01	3.62	92	103
Acid phosphate and AlCl <sub>3</sub> .....	3.10	0.26	0.09	0.04	0.01	3.50	100	100

In these cases the acidity of the resultant extraction solution was a very insignificant factor in modifying the phosphorus recovery, as one notices in figure 1. Taking silica flour treated with phosphorus alone, a standard or a check, calcium carbonate alone reduced the strength of the acid without reducing the phosphorus recovery. Silica treated with ferric chloride(alone)

showed an increase in acidity. In both of these cases the recovery stood practically unchanged or slightly reduced. With a reduction in acidity in the silica treated with ferric chloride and calcium carbonate, the reduction of phosphorus recovery was very pronounced. The extreme case was observed in silica treated with ferric and aluminum chlorides, where a considerable depression in phosphorus recovery was accompanied by the greatest acidity in the extraction solution. Other forces, evidently, were at work that influenced the phosphorus recovery to a greater extent than the change in the acidity strength.

Just what takes place when any of these salts are present with the phosphatic fertilizer, is difficult to say. In the presence of iron, ferric phosphate

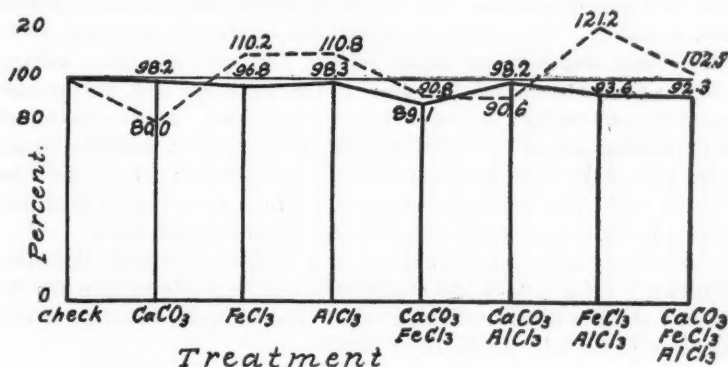


FIG. 1. EFFECT OF FERRIC CHLORIDE, ALUMINUM CHLORIDE AND CALCIUM CARBONATE SINGLY AND IN DIFFERENT COMBINATIONS, ON THE PER CENT OF PHOSPHORUS RECOVERY BY MEANS OF 0.2N HNO<sub>3</sub> FROM FINE SILICA FLOUR TREATED WITH FINELY GROUND ROCK PHOSPHATE

Heavy solid line represents values in phosphorus recovery expressed in percentage of that in check.

The broken line represents values of acidity in resultant extracted solution expressed in percentage of that in check.

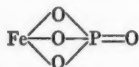
is undoubtedly formed. A similar salt is formed with aluminum. An excess of calcium would tend toward the formation of tricalcium phosphate. These salts, however, go into solution on shaking for 3 hours in 0.2 N HNO<sub>3</sub> to the extent of 95-98 per cent, as reported previously (2). This is substantiated in the present experiment. When iron and aluminum are present together, the phosphorus recovery is inhibited. Could it be possible that a double phosphatic salt of iron and aluminum is formed, which would be more stable than either ferric or aluminum phosphate alone?

The perusal of chemical textbooks and reference books on the subject failed to locate any evidence that a double salt of this composition was ever recorded. The data here obtained, however, tend to show that this might

be the case when both of these elements are present in a position for any regrouping in the molecular structure of their respective salts.

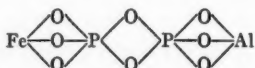
It is a well known fact that some double salts are even more soluble than the respective single salts entering into their composition. For instance ferrous sulfate (1) has a solubility in water of 20.85 per cent at 10°C. Potassium sulfate, at the same temperature, has a solubility in water to the extent of 9.22 per cent. Ferrous potassium sulfate, however, at the same temperature dissolves in water to the extent of 24.5 per cent, showing that more sulfur will be in solution in the double salt than in either of the two single salts. On the other hand, there are salts whose solubility decreases when they form a double salt. Thus, aluminum potassium sulfate is less soluble, taking sulfur as a unit of measure, than aluminum sulfate, and potassium sulfate taken separately. Their respective solubilities per 100 gm. of water at 10°C. is as follows: aluminum potassium sulfate, 7.60 gm.; aluminum sulfate, 33.5 gm.; potassium sulfate, 9.22 gm. In this particular case, the decrease in solubility on forming a double salt is very pronounced. In case of a change from potassium sulfate to potassium alum, the decrease in solubility equals 18 per cent, while from aluminum sulfate to potassium alum, the decrease is 77 per cent. The latter decrease in solubility is much greater than that reported in the present study with iron and aluminum phosphates.

It stands to reason, therefore, that such a double salt of ferric aluminum phosphate is being formed and evidently it is more stable in its molecular structure than its component single salts. The molecular structure of iron phosphate is generally presented as follows:



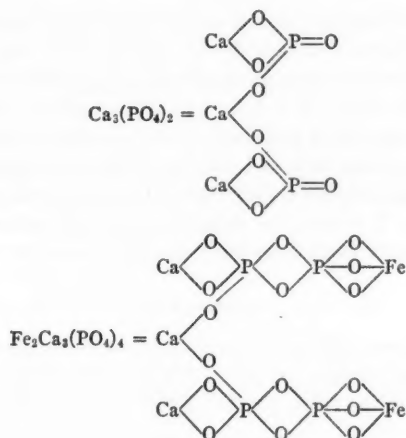
A similar structure is also conceivable for aluminum phosphate.

To form a double salt the elements may regroup themselves somewhat as follows:



It is very reasonable to suppose that such a double salt of phosphate would be more stable, on account of the locking of oxygen between two phosphorus atoms, than the single phosphate of either iron or aluminum.

Turning our attention to tricalcium phosphate, and to the formation of double phosphate with iron, the respective structural formula may assume the following forms:



The suggestion above offers a plausible explanation of the results obtained with soil and silica flour treated with various salts here recorded. It explains why there was a difference in the phosphorus recovery from phosphate treated soils as reported in previous paper (2). There are nearly always present soluble salts of either calcium or aluminum, or both, one of which might form a double salt with the iron, and thus reduce the phosphorus availability in phosphorus treated soil. On addition of more ferric chloride, iron would tend to dominate the regrouping of phosphorus molecules, thus still further reducing the phosphate recovery.

Soil silicates, soluble in 0.2 *N*  $\text{HNO}_3$ , may contribute considerably to the results here obtained. Similarly, silicates present in soils in colloidal solutions, may have similar effect on the solubility of phosphates.

The data presented above suggest the following practical consideration. In order to utilize soil phosphorus or phosphorus from an applied phosphatic fertilizer, a given soil should be managed in such a way that it will not have iron in a soluble form to any appreciable extent. This would tend largely to prevent the formation of the extremely insoluble iron aluminum phosphate. Such a favorable condition would be maintained if the soil solution is kept at about its neutrality. Natural soil acidity tends to render the iron and aluminum more soluble, thus increasing the danger of locking of the available phosphorus in the form of double phosphate of iron and aluminum. On the other hand, a large amount of calcium carbonate in the soil tends to neutralize the soil-forming acids so quickly and so completely that the phosphorus availability becomes inhibited (2, p. 54).

Turning attention to aluminum chloride, one notices that its effect in no way resembles that of iron chloride. Present alone, aluminum chloride in silica flour has no effect on the phosphorus recovery. Present in combination with calcium carbonate, it is also without any appreciable influence.

Upon adding a small amount of this salt to soils, it had even a stimulating effect on the phosphorus recovery in two of the three soils studied. It is evident that in this respect aluminum salts have properties very unlike those observed in salts of iron. If it forms double phosphate with calcium, the behavior of this compound is not similar to that formed by iron and calcium.

In conclusion, it should be noted that in all respects, phosphorus behaved in soil, as well as in sand, in precisely the same way regardless of the source of phosphorus; that is to say, the phosphorus recovery was no greater from double acid phosphate than from finely ground Tennessee rock phosphate.

#### SUMMARY

1. Ferric chloride on addition to three different soils caused a decrease in phosphorus recovery by means of 0.2 *N* HNO<sub>3</sub>, phosphorus being previously applied to the soil in the form of either Tennessee rock phosphate or double acid phosphate.

2. Aluminum chloride, applied to the same soils, showed no depressive effect on the phosphorus recovery. On the contrary, in two out of three cases, it slightly increased the phosphorus recovery.

3. When either CaCO<sub>3</sub>, FeCl<sub>3</sub> or AlCl<sub>3</sub> was applied to fine silica flour (all passing through a 200-mesh sieve) treated with rock phosphate, it did not significantly affect the phosphorus recovery. The application of a mixture of CaCO<sub>3</sub> and FeCl<sub>3</sub>, of FeCl<sub>3</sub> and AlCl<sub>3</sub>, and also of CaCO<sub>3</sub>, FeCl<sub>3</sub> and AlCl<sub>3</sub>, caused some decrease in the phosphorus recovery. The influence of application of a mixture of CaCO<sub>3</sub> and AlCl<sub>3</sub> was much smaller in this respect.

4. It is suggested that double salts of phosphates may be formed; in some cases they may be less soluble than the corresponding single salts. FeAl (PO<sub>4</sub>)<sub>2</sub> may be somewhat more insoluble than either FePO<sub>4</sub> or AlPO<sub>4</sub>. Structural formulas harmonizing with this hypothesis are suggested.

5. In repeated extractions with fresh nitric acid, phosphorus from iron treated soil goes into solution. In five consecutive extractions, practically the same amount of phosphorus was extracted, whether the initial treatment was iron chloride or aluminum chloride.

#### REFERENCES

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# SYNTHETIC CALCIUM SILICATES AS A SOURCE OF AGRICULTURAL LIME: I. A COMPARISON OF THE INFLUENCE OF SYNTHETIC CALCIUM SILICATES WITH OTHER FORMS OF LIME AS AFFECTING PLANT GROWTH<sup>1</sup>

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## INTRODUCTION

From data obtained by numerous investigators, there is good reason to doubt the superiority of one liming material over another when the different materials are applied on an equivalent CaO basis. Therefore, the selection of a liming material by the individual must be an economic one, depending largely on the price of the various materials and their relative content of lime or other bases; the distance of the haul, etc. Frear (5) and Kopeloff (8) give reviews of the extensive literature on the comparison of the various liming materials in their effects upon plant growth.

The literature relative to the use of silicates as carriers of bases for the soil is not so extensive. Grégoire (6) found from water-culture experiments that calcium and sodium zeolites stimulated both root and aerial development of rye. Mieth (11) observed that the calcium of various lime silicates was available to oats grown in water cultures.

MacIntire and Willis (10) compared silicates and carbonates as sources of lime and magnesia for plants in pot studies and came to the conclusion that the mineral calcium and magnesium silicates, wollastonite and serpentine, were very beneficial when applied either singly or jointly. The natural calcium silicate proved decidedly superior to an equivalence of calcium carbonate. However, these investigators used applications of calcium carbonate as high as 16,070 pounds above the requirement as estimated by the Veitch method. They likewise attribute the long continued effects of liming in small or moder-

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ate amounts to a conservation of the lime as silicates in the soil. Ames (1) reports pot experiments comparing basic slag, calcium carbonate, and a calcium silicate on the growth of clover on soil from the Wooster farm. The soil gave a good growth of clover without treatment, but the calcium silicate showed an increase of 42.6 per cent over the untreated soil. The materials were each applied at the rate of 4400 pounds per acre. Cowles (4) and Scheidt (12) report the results of vegetation experiments on an acid soil which had been treated with calcium carbonate, calcium hydrate, and di-calcium silicate on an equivalent CaO basis. From a number of tests with numerous plants, the authors came to the conclusion that di-calcium silicate was superior to the other forms of lime used, attributing the superior results obtained partly to the silica content of the di-calcium silicate. The di-calcium silicate used by these investigators is the same as that employed in the studies reported in this paper. Hartwell and Pember (7) studying the same silicate, arrive at the conclusion that it is as effective as limestone in overcoming the toxic conditions in an acid soil, but that there is no justification in claiming additional value because of the silica content of the material.

Connor (2) used a calcium silicate ( $\text{Ca}_2\text{SiO}_4$ ) on an acid black sand soil and obtained greater crops of beets, corn, and oats than from an equivalent amount of calcium hydrate. He explained the beneficial effects of the silicate as due to the insolubility of the aluminum silicate derived from the silicate as compared with the aluminum hydrate formed on the addition of calcium hydrate. Field tests reported in the same paper show that the calcium silicate compared quite favorably with limestone in correcting the unfavorable conditions for the growth of oats, hay, and corn on a soil at Wanatan. Schollenberger (13) from a series of pot tests with laboratory-prepared calcium silicate obtained increased crop yields and results superior to those obtained from additions of calcium carbonate.

From the fore-going résumé of the literature of the subject, it may be concluded that calcium and magnesium in the form of silicates are active for the correction of the soil condition called "acid," and are therefore beneficial to plant growth.

With these previously conducted experiments in mind, the value of two synthetically prepared calcium silicates as carriers of agricultural lime has been investigated. A comparison of these silicates with other carriers of lime has been made at the New Jersey Agricultural Experimental Stations. The results will be presented in three papers, the first of which deals with the influence of the synthetic calcium silicates upon plant growth, the subsequent papers being an attempted analysis of the factors contributing to the influence on plant growth.

#### DESCRIPTION OF SILICATES

So-called "di-calcium silicate" ( $\text{CaO}$ )<sub>2</sub>SiO<sub>2</sub> is a product prepared in a process described by Cowles (3). The product contains about 80 per cent di-calcium

silicate and relatively large percentages of sodium and aluminium compounds as impurities.

The second silicate—called "limosil" for lack of a better name—is prepared in a process for the recovery of potash from glauconite. One description of this process is given by Shreve (14). From the nature of the reaction between calcium hydrate and glauconite, the inventors of the process are under the impression that a mono-calcium silicate is formed. Beside the mono-calcium silicate, the material contains about 13 per cent free lime in the form of calcium hydrate. However, analyses show that upon drying and standing the calcium hydrate becomes slowly carbonated.

The following are typical analyses of these synthetic silicates:

	DI-CALCIUM SILICATE	LIMOSIL
	<i>per cent</i>	<i>per cent</i>
Silica ( $\text{SiO}_2$ ) . . . . .	30.34	25.62
Iron oxide ( $\text{Fe}_2\text{O}_3$ ) . . . . .	2.03	9.02
Calcium oxide ( $\text{CaO}$ ) . . . . .	49.14	40.95
Free lime . . . . .		13.05
Magnesium oxide ( $\text{MgO}$ ) . . . . .	3.26	
Sodium oxide . . . . .	6.01	
Alumina ( $\text{Al}_2\text{O}_3$ ) . . . . .	7.07	
Total potash ( $\text{K}_2\text{O}$ ) . . . . .		1.90
Soluble potash . . . . .		0.23
Phosphoric acid ( $\text{P}_2\text{O}_5$ ) . . . . .		0.14

These silicates have been compared with other forms of lime in a number of pot and field experiments the results of which follow. Due to the relatively large number of tests conducted, the averaged results are usually given, thus eliminating a great mass of data which would otherwise be very ineffectively handled.

#### EXPERIMENTAL RESULTS AND DISCUSSION

##### *Series I*

The comparative effects of ground limestone, calcium hydrate, and di-calcium silicate on plant growth in a loam soil were tested by the ordinary pot-culture method. The pots used were glazed inside and out and were of two sizes—18- and 10-pound capacities. The soils used were removed from plot N and plot 11A of the unlimed series of the New Jersey Experiment Station plots. A description of the soil from plot 11A, together with the fertilizer and cultural treatments, has been reported in Bulletin 260 (9) of the New Jersey Station. The soil represented by plot N has received no commercial nitrogen for more than ten years. It has not been limed for a longer period, possibly 20 or 25 years. It has received annual applications of acid phosphate at the rate of 300 to 400 pounds, and muriate of potash at the rate of 100 to 200

pounds per acre for the past 15 years. The soil showed a lime requirement by the Veitch method of 2000 pounds of CaO per acre at the time of removal in 1920. The soil of plot 11A has received applications of acid phosphate, muriate of potash and ammonium sulphate since 1908 and showed a lime requirement by the Veitch method of slightly over 2000 pounds of lime (CaO) per acre when removed from the plot in 1920.

After removal from the plots, the soil was screened, thoroughly air-dried, and weighed into tared pots. The liming materials<sup>4</sup> were carefully weighed and were thoroughly mixed throughout the entire mass of soil before the addition of water. All materials were applied at the rate of 2000 pounds of CaO per acre of 2,000,000 pounds. A moisture content of 60 per cent of the maximum water-holding capacity (Hilgard) was maintained throughout the experiment.

Duplicate pots of the soil from plots N and 11A were seeded to soybeans, barley, and buckwheat on October 16, 1920, and on November 1, 1920, respectively. When the seedlings were well above the ground they were thinned to a constant number per pot: 6 of soybean, 12 of barley, and 8 of buckwheat. The plants of plot-N group were harvested after 9½ weeks and those of the plot-11A group, after 13 weeks. No attempt was made to remove the roots from the soil. The dried plants were milled to a fine powder and the nitrogen-content determined by the Kjeldahl method. After the first crop, 2 gm. of acid phosphate, 2 gm. of dried blood and 1 gm. of potassium chloride were mixed throughout the soil. In each pot 8 plants of buckwheat were grown.

The relative dry weights and total nitrogen results are given in tables 1 and 2 respectively.

The soybean showed practically the same response to ground limestone, di-calcium silicate and calcium hydrate. However, the di-calcium silicate proved distinctly superior for the buckwheat which followed the soybeans grown on the soil from plot 11A. On both soils di-calcium silicate was distinctly beneficial to barley. This may be attributed to the reactivity of the added silica. The silicate also appears to be superior to the other forms of lime as judged by the yield of buckwheat following the barley on both soils. Calcium hydrate proved to be more effective upon the first crop of buckwheat, but for 2 successive crops of buckwheat, the di-calcium silicate was superior on both soils, especially on the soil from plot 11A. When the relative yields of all the crops are averaged, the di-calcium silicate proves to be the more effective on both soils. On the soil from plot N, the calcium hydrate and ground limestone gave practically the same results, however on the more acid soil from plot 11A the calcium hydrate proved better than ground limestone. The averaged relative yield of all crops on both soils shows that di-calcium silicate is more efficacious

<sup>4</sup> Analyses of materials used:

	CaO per cent
Ground limestone .....	52.41
Di-calcium silicate .....	44.52
Calcium hydrate .....	72.95

than is calcium hydrate in overcoming the unfavorable condition in the so-called "acid" soils, while the hydrate proved more effective than ground limestone.

The nitrogen content of the plants grown in the unlimed soils was higher than of those grown in the limed soils in every case except that of buckwheat

TABLE 1

*Relative dry weights of soybeans, barley and buckwheat grown on soils from plot N and plot 11A treated with ground limestone, di-calcium silicate and calcium hydrate*

TREATMENT	SOYBEAN FOLLOWED BY BUCKWHEAT		BARLEY FOLLOWED BY BUCKWHEAT		BUCKWHEAT FOLLOWED BY BUCKWHEAT		AVERAGED RELATIVE YIELD, ALL CROPS	AVERAGED RELATIVE YIELD, FIRST 3 CROPS, BOTH SOILS	AVERAGED RELATIVE YIELD, ALL CROPS, BOTH SOILS
	Soybean	Buckwheat	Barley	Buckwheat	Buckwheat	Buckwheat			
<i>Loam soil from plot N†</i>									
	(2.06 gm.)	(6.09 gm.)	(2.02 gm.)	(7.09 gm.)	(1.71 gm.)	(2.64 gm.)			
No lime . . . . .	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
* 16.3 gm. ground lime- stone . . . . .	324.3	255.9	442.4	192.6	341.5	595.5	358.7	494.8	574.0
* 19.2 gm. di-calcium sili- cate . . . . .	347.9	247.9	719.8	229.2	359.3	663.9	428.0	614.5	713.8
* 11.7 gm. calcium hy- drate and 4.27 gm. hy- drated silica . . . . .	328.9	243.8	530.5	196.3	445.0	622.4	394.5	576.5	624.8
<i>Loam soil from plot 11A‡</i>									
	(1.68 gm.)	(1.27 gm.)	(1.50 gm.)	(1.54 gm.)	(0.74 gm.)	(0.69 gm.)			
No lime . . . . .	100.0	100.0	100.0	100.0	100.0	100.0	100.0		
* 9.06 gm. ground lime- stone . . . . .	519.7	1,081.9	248.0	561.6	1,093.2	1,231.2	789.3		
* 10.66 gm. di-calcium silicate . . . . .	509.8	1,343.9	420.1	850.8	1,330.4	1,539.7	999.1		
* 6.50 gm. calcium hy- drate . . . . .	529.9	1,090.5	262.0	589.3	1,362.8	1,296.0	855.1		

\* Equivalent to 2000 pounds of CaO per acre.

† Eighteen pounds of soil per pot.

‡ Ten pounds of soil per pot.

from 11A. However, the total nitrogen recovery in the limed crop exceeded that of the control because of greatly increased yields. The percentage of nitrogen in the soybeans grown on the untreated soil from plot 11A is higher than the results obtained by other investigators. However, the percentages of nitrogen are in accordance with those obtained by Voorhees and Lipman (15). These investigators, state:

As time went on the lack of available phosphoric acid was felt more and more in the soils of series 1 and the amount of available nitrogen present became greater than the minimum required for the production of the corresponding amounts of dry matter. As a necessary consequence of this situation, the dry matter of series 1 contained what may be termed an abnormally high proportion of nitrogen.

Under the conditions of the present experiment, there should be no deficiency of phosphoric acid or potash. It is conceivable, however, that there can be present in the soils a greater proportion of available nitrogen than is neces-

TABLE 2  
*Relative total nitrogen content of soybeans, barley, and buckwheat grown on soils from plot N and from plot 11A untreated, and treated with various liming materials*

TREATMENT	RELATIVE TOTAL NITROGEN CONTENT			AVERAGED RELATIVE TOTAL NITROGEN CONTENT			AVERAGED RELATIVE TOTAL NITROGEN CONTENT, ALL CROPS	AVERAGED RELATIVE TOTAL NITROGEN CONTENT, ALL CROPS ON BOTH SOILS
	Soybean	Barley	Buckwheat	Soybean	Barley	Buckwheat		
<i>Loam soil from plot N</i>								
	(0.09 gm.)	(0.06 gm.)	(0.032 gm.)					
No lime.....	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
* 16.3 gm. ground limestone...	259.3	437.5	433.0	267.5	279.1	633.4	376.6	393.3
* 19.2 gm. di-calcium silicate...	280.7	491.1	514.6	265.9	338.8	782.3	428.8	467.3
* 11.7 gm. calcium hydrate and 4.27 gm. hydrated silica.....	277.5	350.6	549.5	247.3	246.7	707.4	392.6	399.4
<i>Loam Soil from plot 11A</i>								
	(0.09 gm.)	(0.03 gm.)	(0.014 gm.)					
No lime.....	100.0	100.0	100.0				100.0	
* 9.06 gm. ground limestone...	275.6	120.6	833.7				409.9	
* 10.66 gm. di-calcium silicate...	250.2	186.5	1,080.9				505.8	
* 6.50 gm. calcium hydrate...	217.0	142.8	865.2				406.3	

\* Equivalent to 2000 pounds of lime (CaO) per acre.

sary for the production of the small growth obtained under the unfavorable condition, whether this unfavorable condition be considered as due to the so-called "acidity" or to a lack of calcium. The fact that the plants took up a large proportion of nitrogen under these conditions may indicate a deficiency of one or more basic elements.

Eleven of the 18 relative total nitrogen recoveries coincided with the order of relative yield of dry matter.

*Series II*

In this series of pot cultures, 3 soils were used. The first soil was obtained from plot 11A of the New Jersey Experiment Station plots described above. The second a loam soil designated as "Sassafras loam" was from an old field near the College Farm. It had not received an application of lime within the last 20 years, having been under sod for a period of years, and showed a lime requirement by the Veitch method of 2000 pounds of CaO per foot-acre of 2,000,000 pounds. The third soil was a Penn loam obtained from a well-limed and flourishing alfalfa field and showed no lime requirement by the Veitch method.

The air-dried soils were passed through a  $\frac{1}{4}$ -inch mesh sieve and 10-pound portions were weighed into glazed pots, duplicate pots being used for each treatment. The liming materials<sup>5</sup> were sieved to the same fineness and incorporated with the soil before water was added. Each pot received an application of acid phosphate at the rate of 600 pounds and muriate of potash at the rate of 200 pounds per acre. The soils were brought to 60 per cent of their respective water-holding capacities and maintained at this point by the addition of distilled water.

The experiment called for: First, a comparison of a 2000-pound CaO-equivalence of limosil, ground limestone, calcium hydrate and di-calcium silicate on all soils; second, a comparison of 500-, 1000-, 2000-, and 4000-pound CaO-equivalence of limosil. Three crops; soybeans, barley, and corn, were grown in order. After the removal of each crop the soil was stirred, screened and placed again in the pots. Only one application of lime or fertilizing salts was made, and the same number of plants were grown in each pot. The soybeans were planted on May 5, 1921, and harvested 9 weeks later; barley was planted on August 22, and harvested after 17 weeks; corn was planted on January 4, 1922, and harvested 6 weeks later. The dry weights of the plants were obtained by drying at 100°C. for several days. The total and relative dry weights of the crops produced on the various soils under the treatments are given in table 3.

The comparison of the materials on the equivalent lime basis indicates that the silicates are as effective as the other forms of lime. Considering the percentage of error in this type of experimentation the fact is emphasized that one type of lime is equally effective with the others in overcoming the deleterious effects of a so-called "acid" soil on plant growth.

The total dry weight of the crops increased with the application of the limosil for all 3 soils. The greatest relative increases were obtained with the

<sup>5</sup> Analyses of materials used:	CaO per cent
Ground limestone.....	56.52
Calcium hydrate.....	75.28
Di-calcium silicate.....	50.93
Limosil.....	40.95

very acid soil from plot 11A. However, the Sassafras loam shows an increase which is well above the error of experimentation. Even the yields on the previously limed Penn loam show a perceptible increase over those from the untreated soil.

### Series III

The comparative effects of calcium oxide, calcium hydrate, ground limestone, di-calcium silicate and limosil on the growth of soybeans and buckwheat in 2 acid soils were studied by the ordinary pot method. The first soil was the Sassafras loam obtained from an old field and described under series II. The

TABLE 3

*Total dry weights and relative total dry weights of 3 crops grown on soils from plot 11A, Sassafras loam, and Penn loam treated with increasing amounts of limosil, and with calcium hydrate, di-calcium silicate, ground limestone, and limosil on an equivalent lime basis*

TREATMENT	EQUIVALENT AP- PLICATION OF CaO PER ACRE	TOTAL DRY WEIGHT OF 3 CROPS*			RELATIVE TOTAL DRY WEIGHT OF 3 CROPS			AVERAGED RELA- TIVE TOTAL DRY WEIGHT
		Soil from plot 11A	Sassa- fras loam	Penn loam	Soil from plot 11A	Sassa- fras loam	Penn loam	
	pounds	gm.	gm.	gm.				
No lime.....		4.24	9.16	12.46	100.0	100.0	100.0	100.0
2.769 gm. limosil.....	500	16.90	14.62	12.68	398.4	159.6	101.8	219.9
5.538 gm. limosil.....	1,000	19.08	15.99	13.52	449.8	174.5	108.5	244.9
11.076 gm. limosil.....	2,000	25.14	17.52	13.54	592.6	191.2	108.7	297.5
22.152 gm. limosil.....	4,000	29.23	22.71	15.08	689.8	247.8	121.0	352.5
11.076 gm. limosil.....	2,000	25.14	17.52	13.54	592.6	191.2	108.7	297.5
8.024 gm. ground limestone....	2,000	26.69	18.57	12.97	629.2	202.6	104.1	311.9
6.026 gm. calcium hydrate....	2,000	27.91	17.16	13.71	657.8	187.2	110.1	318.4
8.904 gm. di-calcium silicate...	2,000	25.70	20.23	14.86	605.9	220.8	119.3	315.3

\*First crop—soybean.

Second crop—barley.

Third crop—corn.

second soil was an acid silt loam soil from an old abandoned field near South River, New Jersey. This soil is classified as "Elkton silt loam." The Elkton silt loam showed a lime requirement of 3200 pounds by the Veitch method.

The materials\* (> 200-mesh) were carefully weighed and mixed with the air-

* Analyses of materials used:	CaO per cent
Calcium oxide.....	100.00
Calcium hydrate.....	75.28
Ground limestone.....	56.52
Di-calcium silicate.....	50.93
Limosil:	
Total.....	40.95
Free.....	13.05

dried soils before water was added. Sufficient CaO was added in the form of the various materials to meet the lime requirement by the Veitch method.

Applications of calcium oxide equivalent to the free lime in the limosil (as indicated in the analyses) were made in order to ascertain if the value of the limosil was dependent on its content of free lime alone or if the calcium silicate also supplied the base. No additions of fertilizing materials were made to the soils.

TABLE 4

*Relative dry weights of buckwheat and soybean plants grown on a Sassafra loam and an Elkton silt loam treated with 5 forms of lime on an equivalent lime (CaO) basis*

TREATMENT	EQUIVALENT APPLICATION OF CaO PER ACRE	RELATIVE DRY WEIGHT		AVERAGED RELATIVE DRY WEIGHT, BOTH CROPS	AVERAGED RELATIVE DRY WEIGHT, BOTH CROPS ON BOTH SOILS	AVERAGED RELATIVE DRY WEIGHT, BUCKWHEAT	AVERAGED RELATIVE DRY WEIGHT, SOYBEANS
		Buckwheat	Soybean				
Sassafra loam							
		(4.49 gm.)	(4.86 gm.)				
No lime . . . . .		100.0	100.0	100.0	100.0	100.0	100.0
3.6117 gm. calcium oxide . . . . .	2,000	141.1	190.0	165.5	256.6	352.8	160.5
4.7976 gm. calcium hydrate . . . . .	2,000	188.8	180.2	184.5	260.5	364.9	156.0
6.4302 gm. ground limestone . . . . .	2,000	218.7	160.5	189.6	251.7	344.9	158.5
7.0916 gm. di-calcium silicate . . . . .	2,000	212.8	168.6	190.7	303.1	423.4	182.7
8.8197 gm. limosil . . . . .	2,000	200.8	178.4	189.6	289.7	395.8	183.5
*0.4713 gm. calcium oxide . . . . .		90.9	113.0	101.9	160.9	199.5	122.2
Elkton silt loam							
		(1.58 gm.)	(4.39 gm.)				
No lime . . . . .		100.0	100.0	100.0			
5.8000 gm. calcium oxide . . . . .	3,200	564.5	130.9	347.7			
7.7126 gm. calcium hydrate . . . . .	3,200	541.0	131.8	336.4			
10.2726 gm. ground limestone . . . . .	3,200	471.0	156.5	313.8			
11.4013 gm. di-calcium silicate . . . . .	3,200	634.0	196.8	415.4			
14.1785 gm. limosil . . . . .	3,200	590.0	188.5	389.7			
*1.8500 gm. calcium oxide . . . . .		308.2	131.3	219.8			

\* Equivalent to the free CaO in limosil.

A crop of buckwheat (4 plants per pot) was planted on December 10, 1921, and harvested  $16\frac{1}{2}$  weeks later. The buckwheat was followed by soybeans, which were planted on April 7, 1922, and harvested after  $12\frac{1}{2}$  weeks. The relative dry weights are given in table 4.

On the Sassafra loam, the ground limestone and di-calcium silicate produced the largest yields of buckwheat; but uniform results were obtained with soybeans. On the Elkton silt loam, the buckwheat grew best in the pots treated

with di-calcium silicate. The soybeans were most favorably effected by di-calcium silicate and limosil. However, considering the averaged results, there is very little difference between the results from the different materials, with the possible exception of di-calcium silicate which produced somewhat larger average yields than the other materials.

A comparison of the yields from the soils treated with limosil, with those obtained from the soils treated with CaO equivalent to the free lime in limosil, shows that the base in combination with the silica is also efficacious in neutralizing the unproductive factors of acid soils.

#### *Series IV*

A field experiment for a test of the comparative effects of the various forms of lime used in the controlled experiments described above was arranged and carried out on 12 plots in 1921 and 1922. Each plot was 16 feet by 13 feet 7 inches ( $\frac{1}{200}$  acre each) with a path of 2 feet between plots. The experiment was carried out on a low, rather poorly drained portion of a field. The soil was acid to litmus and was overgrown with weeds at the time the experiment was started in May. The soil is usually classified as a Sassafras loam, and is the same as that of the New Jersey plot experiments.

A general fertilizer treatment of acid phosphate at the rate of 300 pounds per acre and muriate of potash at the rate of 50 pounds per acre was made to the plots. Five treatments of different liming materials<sup>7</sup> were made in duplicate on May 9, 1921. These materials were added at the rate of 1000 pounds of CaO per acre. They were thoroughly worked into the soil with a disc harrow. Soybeans were planted on June 27, and harvested on October 4, 1921. Without further treatment to the soil, buckwheat was planted as the 1922 crop. It was planted on May 15 and harvested on July 21. The paths between the plots were cut wider in the harvest of this crop, but due allowance has been made in calculating the results. The application of the various materials used and the green weights (average of 2 plots), together with the calculated yields per acre and the relative yields are given in table 5.

The ground limestone and di-calcium silicate show better results with the soybeans, while the other materials are very like in their effect on the growth of this plant. The most striking result with the buckwheat is the very low relative yield obtained with the limosil. The averaged relative yields of the 2 crops show that ground limestone, calcium hydrate and di-calcium silicate are about equally effective, while limosil and the Medford residue lime are decidedly lower.

<sup>7</sup> Analyses of materials used:

	CaO per cent
Ground limestone.....	50.00
Calcium hydrate.....	74.23
Di-calcium silicate.....	52.20
Limosil.....	40.95
Medford residue lime.....	15.92

As a further test of the comparative effects of ground limestone, calcium hydrate and limosil on plant growth, a field experiment was conducted on a Penn loam soil. The field had been under grape culture for several years and was decidedly acid. Plots 18 by 70 feet with 3-foot paths were laid out.

TABLE 5  
*Yields and relative yields of soybean and buckwheat crops grown on small plots*

TREATMENT	1921 CROP SOYBEANS			1922 CROP BUCKWHEAT			AVERAGED RELATIVE YIELD, BOTH CROPS
	Aver- aged yield per plot*	Calcu- lated yield per acre	Rela- tive yield	Aver- aged yield per plot†	Calcu- lated yield per acre	Rela- tive yield	
	pounds	tons		pounds	tons		
No lime . . . . .	39.75	3.98	100.0	19.00	2.19	100.0	100.0
Calcium carbonate . . . . .	54.88	5.49	138.0	29.13	3.31	153.3	145.7
Calcium hydrate . . . . .	48.38	4.84	121.7	29.75	3.43	156.6	139.2
Di-calcium silicate . . . . .	54.50	5.45	137.1	27.30	3.14	143.7	140.4
Limosil . . . . .	48.13	4.81	121.1	20.13	2.32	105.9	113.5
Medford residue lime . . . . .	49.33	4.93	124.1	23.63	2.72	124.1	124.3

All lime treatments made at rate of 1000 pounds CaO per acre.

\* Average of 2 plots—16 feet by 13 feet 7 inches, or  $\frac{1}{200}$  acre each.

† Average of 2 plots—14 feet by 13 feet 7 inches, or  $\frac{1}{230.4}$  acre each.

TABLE 6  
*Relative yields of crops grown on small plots of Penn loam on College Farm*

TREATMENT	SOYBEAN*			CORN*			OATS† AND BARLEY	AVER- AGE ALL CROPS
	Beans	Stalks	Aver- age	Grain	Forage	Aver- age		
		(11.81 bushels per A.)	(1132 pounds per A.)	(88.3 bushels per A.)	(4542.5 pounds per A.)		(2047.1 pounds per A.)	
No lime . . . . .	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ground limestone . . . . .	213.9	191.3	202.6	118.6	113.9	116.3	129.5	149.5
Calcium hydrate . . . . .	203.2	166.8	185.0	112.8	88.6	100.7	179.5	155.1
Limosil . . . . .	188.1	166.8	177.5	131.4	106.3	118.9	153.3	149.9

Applications of liming materials at rate of 2000 pounds CaO per acre.

\* Plots 18 feet by 21 feet, or  $\frac{1}{115}$  acre each.

† Plots 18 feet by 13 feet, or  $\frac{1}{186.1}$  acre each.

Applications of ground limestone, calcium hydrate, and limosil were made at the rate of 2000 pounds of CaO per acre without fertilizer.

These larger plots were divided into smaller areas depending upon the crop planted, permitting 3 crops for each of the several liming materials. One area was seeded to each: oats and barley mixture, soybeans, and corn. The

oats and barley mixture was planted on May 2, and harvested on July 21, 1922. The soybeans and corn were planted May 25 and harvested on October 20, 1922. The beans were thrashed and the weight of the stalks and beans determined separately. The corn was dried and shelled. The relative yields with the calculated yield per acre of the unlimed plots are given in table 6.

The crop increase on the limed soil over that of the untreated is quite marked in every instance, except that of the corn plot treated with calcium hydrate. Taking all the crops into consideration it is interesting to note that the difference in the average relative yields of the 3 crops is easily within the error of this type of experimentation, with no determined advantage of one material over the other. This is in entire accord with the previously described pot experiments.

#### CONCLUSIONS

The growth of several plants as influenced by equivalent applications of lime in various forms, on several acid soils, has been studied under controlled conditions (pot experiments) and also by means of field experiments. The studies were made with particular reference to calcium silicates as possible carriers of lime. The following are the general conclusions from the studies:

1. As a whole, the artificial calcium silicates were as effective as the common forms of lime in overcoming the unproductive condition of so-called "acid" soils when applied on an equivalent CaO basis.
2. The greatest deviation from the above generalization occurred in the exceptional increase in the growth of barley on soils treated with di-calcium silicate. The greater barley yields obtained with the silicate might possibly be due to the greater absorption of the silicon of the silicate, resulting in a healthier and heavier plant.
3. The percentages of nitrogen in the soybean, barley, and buckwheat plants varied with the soil, the higher percentages having been found under the more unfavorable conditions of the untreated or so-called "acid" soils. The treatments of limestone, calcium hydrate and di-calcium silicate gave crops of closely comparable nitrogen content. The greatly enhanced growth on the limed soils always netted a greater recovery of nitrogen.

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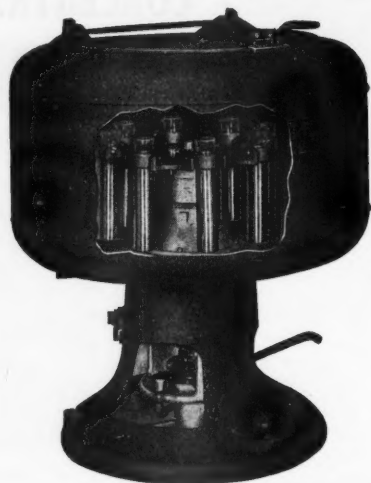
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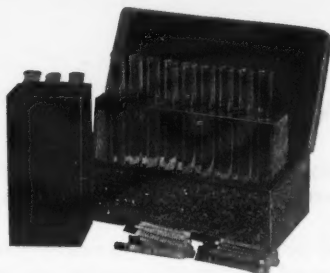
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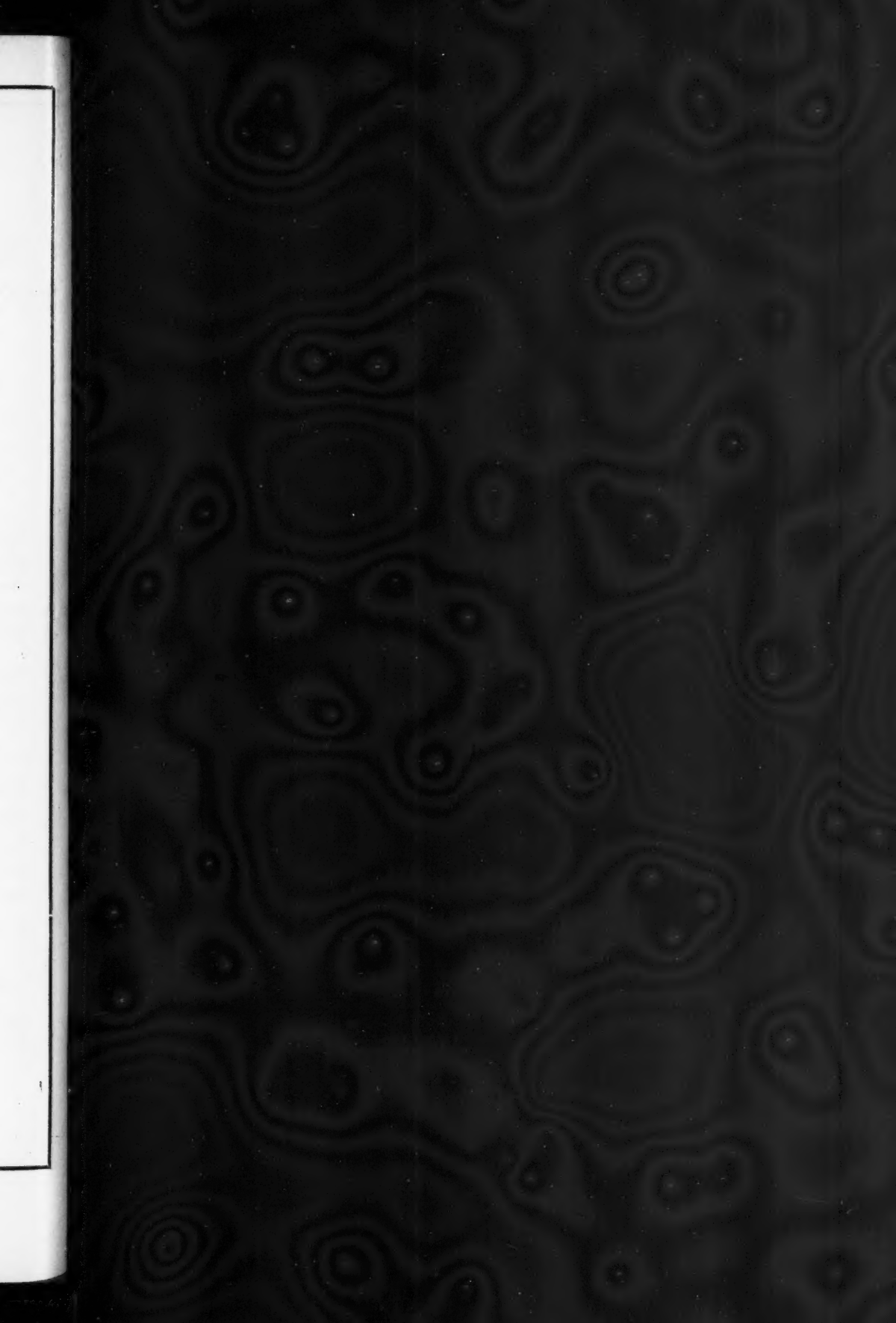
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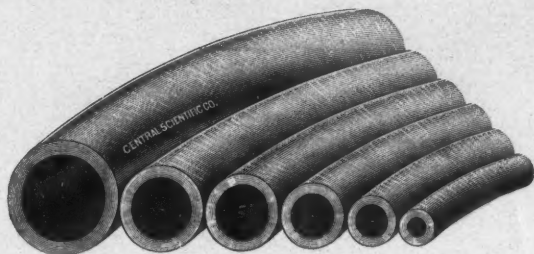




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